ERB 76-205

GEOTHERMAL APPLICATION FEASIBILITY STUDY FOR THE NEW MEXICO STATE UNIVERSITY CAMPUS

TECHNICAL REPORT
(9/15/76-9/14/77)

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EXECUTIVE SUMMARY

New Mexico State University is currently using natural gas at a rate of 290 million cubic feet per year and electricity at the rate of 51 million Kilowatt-hours per year. Not only has the cost of these energy resources increased several-fold in the past five years, but, in the case of natural gas, the threat of a cut-off in supply during a peak demand period is very real. Thus, both for economic reasons, benefitting the taxpayers of the State of New Mexico, and for the purpose of providing uninterruped services to the public, NMSU must search for alternate energy resources.

The present project exploring alternatives for use of geothermal energy on campus was prompted by the needs just described and the belief, based on geochemical survey, that a substantial geothermal resource exists on NMSU property, not far from the main part of campus. The purpose of the project was to better define the potential resource and to examine alternatives for its use from a technical-economic standpoint. Various assumptions were to be made about the temperature and pumping capacity of the resource. Conceptual engineering designs and preliminary legal and environmental assessments were two of the objectives.

The results of the investigation are favorable and can be conveniently divided into two classes: 1) Geothermal resource assessment and 2) Technico-economic assessment of possible applications on campus.

Two members of the study team obtained and analyzed extensive additional data concerning the potential geothermal resource located

southeast of the University Golf Course and west of Tortugas Mountain, principally on University property.

The information involved included: 1) The geochemistry survey previously mentioned, 2) an extensive surface thermal mapping conducted by one of the investigators, 3) electrical resistivity data from a study in progress by an investigator at another New Mexico institution, and 4) information on several shallow wells and one deep well previously drilled in the general area of interest. The geophysical, geochemical and drilled wells information all indicate that an aquifer, several square miles in area, perhaps 300-400 feet in thickness, containing water at 60-100°C with about 2500 ppm dissolved solids, exists on University property (and adjacent State and private lands) at a depth of 600-2000 feet. Only a test well, which hopefully could become a production well, could provide fully definitive information on the temperature, quality and production rate of the resource.

The conceptual engineering designs and technico-economic analysis reveal several financially attractive campus applications which should be feasible with "off-the-shelf" technology. The most desirable application, which will yield the greatest savings with the least investment, is using the geoheat for providing the majority of the domestic hot water used on campus. This application would reduce natural gas consumption by 30 to 40 percent and would pay for the cost of installation, with interest, in less than five years. If the flow rate of the resource is large enough, 90 percent of the campus heat needs could be converted to geothermal. This would require considerable investment but a net savings is predicted within a period of less than ten years. Other applications considered were electric power generation and provision of chill water for building cooling. The first is not feasible with current technology. Unless the water in the geothermal resource is considerably hotter than expected, the cooling option is also not viable from an energy-savings or economic viewpoint, given current technology.

Preliminary legal-environmental assessments indicate no impediments to utilization of the resource by the University.

It is recommended that the next stages, drilling of a deep test well and detailed engineering design, be pursued as soon as possible.

SECTION I

A GEOTHERMAL PROSPECT CONCEPTUAL STUDY FOR NMSU CAMPUS

INTRODUCTION

The impetus for the present feasibility study for use of geothermal heat on the NMSU campus comes from global, national and local concerns. There is a growing global supply/cost problem regarding fossil fuel. Nationally, the Gross National Product and the behavior of the entire economy is being adversely affected by the cost of imported petroleum energy supplies and the consequent extraordinary deficit in the international balance of payments. Locally, energy costs at NMSU have quadrupled in five years and no assurance of adequate supply of natural gas for heating classrooms and dormitory buildings can be made if an extreme "cold spell" occurs.

Energy is more than just another scarce resource; it is the world's basic commodity. The U.S., as user of over one-third of the world's energy, is the leading energy consumer. U.S. energy consumption has been growing exponentially throughout most of the nation's history. Although it is recognized that no finite system can maintain exponential growth forever, it is yet to be determined how, when, and why the growth in energy consumption will slow down or stop. While energy use today is not necessarily reaching an absolute maximum, there is need for careful study of a wide range of factors and options inherent in energy-use patterns.

Through 1973 the cost of energy based on the global oil market was low and there was little incentive for industrialized nations to develop efficient conservation methods and/or alternate energy sources. Cheap energy ceased to exist when the price of crude oil from the Middle East quadrupled during a few months in 1974. This action resulted from the understanding of leaders of oil producing and exporting countries that their product was currently undervalued, that it was non-renewable and that it would necessarily be replaced, in time, with alternate energy sources.

The oil embargo encouraged the industrialized nations to attempt to establish effective conservation measures and to develop alternate energy sources. In the U.S. there was a sharp decline in oil consumption immediately following the emergency. Unfortunately, as the urgency of the emergency eased, so did the conservation efforts. While the declared policy of the U.S. was to strive for total energy "self-sufficiency", more crude petroleum was imported in 1976 than in 1975 and little was done to encourage exploration and production of domestic oil and alternate energy resources. Since 1974, only modest dollar increases in State and Federal R & D support have been directed toward the development of alternate energy sources. Global energy shortages will continue to exist - probably until the end of this century - unless new energy sources are developed and new energy technologies are put to work for production of electricity and replacement of conventional heating and cooling systems using fossil fuel.

Geothermal energy is definitely becoming a viable contributor to U.S. energy resources. However, its exploration must be accelerated if it is to contribute to domestic self-sufficiency of U.S. energy needs.

The use of geothermal energy is not a new one; it has been used for home heating in a few U.S. locations since 1900, heating in Iceland since the 1930's and for electrical power production in Larderello, Italy, since 1904.

The U.S. resource of geothermal energy has been compared favorably with present oil and gas reserves. It is believed that most suitable exploitable geothermal energy fields are located in the western parts of the U.S. Its development could have considerable impact on meeting the energy needs of the U.S.

Geothermal energy is the energy provided by the heat of the earth. Earth's heat reaches near surface by thermal conduction through solid rock or by slow cooling of intruding magma. Deep circulating meteoric water brings this energy to the surface or within economically-exploitable depth. This heat constitutes the geothermal energy base. Most of this heat is too diffuse to be of economic value, but sufficient concentration of geothermal heat has been delineated to give knowledge that sufficient reserves of geothermal energy may be extracted from this base. The characteristics of geothermal reservoir, viz. temperature, pressure, volume, depth, extent, and hydrology, determine its economic extraction and exploitation. Geothermal reservoirs are classified by temperature, depth, availability and salinity of water. These factors determine the cost of field development, physical and chemical and environmental problems of production and the forms of utilization. The classification of geothermal energy resources as proposed by White [1] is as follows:

1. Vapor-dominated hydrothermal systems
2. Liquid-dominated hydrothermal systems
    a. High-temperature system (T>180°C)
    b. Low-salinity (TDS<20,000 ppm)
    c. High-salinity (TDS>20,000, ppm and usually 100,000 ppm)
3. Moderate temperature systems (100-180°C)
4. Low-temperature convection systems (T<100°C)

5. Geopressured deposits

6. Hot dry rock formations

7. Near "normal" thermal gradient environments

An energy system will normally consist of one or more sources of energy supplying different types of energy. Some types of energy will be transformed into a different type before the eventual use. Typical energy sources are: electricity, fossil fuel, gas, wool, coal, etc. Electricity is generally supplied by an electric utility company; however, a user may sometimes produce electricity for his own use. Electricity is generated by converting some other form of energy such as chemical energy in fossil fuels, gas, coal, etc., or kinetic energy of water, or solar energy, etc. Use of electricity has gained wide acceptance due to the high efficiencies that can be attained for transporting it over reasonable distances, but the total energy efficiency from primary fuel in end use is quite low.

Typical uses of energy are heating, cooling, lighting and other residential and industrial uses. Acceptance of electricity for lighting is almost universal and definitely a fact of life in this country. Heating and cooling can be provided with electricity, fossil fuels, gas, coal, etc.

Geothermal energy, wind energy, and solar energy are possible sources which can be used for numerous non-mobile applications with further development of associated technologies and with reduction in the costs involved. Since the costs of traditional sources have been increasing rapidly, with indications that these trends will continue in the future, use of geothermal, wind, and solar energy is bound to become relatively cheaper.

This report undertakes to investigate and design a geothermal energy system to meet the needs of a moderate-sized university campus such as NMSU. The energy needs for the NMSU campus are substantial inasmuch as its total electricity bill for 1976 was well in excess of 1 million dollars and the total natural gas bill for 1976 was in the vicinity of 400,000 dollars. Considerable price increases are imminent and the supplier (City of Las Cruces) of gas to NMSU does not guarantee the delivery of the required volume of natural gas during future winter seasons. Therefore, it is imperative that an alternate energy source be investigated for possible adoption.

BACKGROUND INFORMATION

Details of previous successful application of moderate temperature geothermal resources to various heating uses are given in the following paragraphs. The advantages and the difficulties as well as methods of coping with the difficulties are described.

T. Boldizsar [2] reported geothermal energy use in Hungary. The Hungarian Plain is a subsistence basin which contains immense quantities of geothermally-heated water, oil and natural gas. About half of the territory of Hungary has the potential to produce geothermal energy or goethermally-heated water. Deep wells are drilled and lined with perforated casings. The hot water goes from the wellhead to concrete tanks where $CaCO_3$ deposits as flakes. The hot waters are alkaline with about 1800 to 2500 ppm soluble ions. Periodic descaling is performed on the upper casing. Combustible gases are separated and used. The 131 wells in Hungary have about 770 MW (thermal) peak potential. District heating and greenhouses utilize the resource at about one-third the cost of using coal. Substantial gas and oil deposits have been revealed while drilling for geothermal resources. Detailed procedures for drilling, casing, and descaling wells and diagrams of district heating systems are included in the paper.

B. Lindal [3] described geothermal energy for process use in Iceland. The industrial processing fields in Iceland uses both hydro-power and geothermal energy with potentials of 35,000 GWh per year and 70 x 10^6 Gcal per year, respectively. The use of geothermal energy has increased in recent years using wet steam up to 185°C and hot water at lower temperatures. The temperature of the geothermal fluid determines the most suitable process use. Multipurpose use of geothermal energy is recommended, including electric power production, space heating and process heating. Entire plant complexes for chemical processing, which are more or less self-sufficient in heat, power and raw materials, have been planned. Corrosion of metals in the systems must be considered, with low carbon steel the most suitable. Established industrial uses of geothermal energy include greenhouses, seaweed drying, hay drying, washing and drying of wool, seasoning and drying of timber, drying of insulation material and stock drying of fish. At Myvatn in northern Iceland, 24,000 tons per year of diatomaceous earth are processed and dried to produce a diatomite filteraid. Seaweed drying and milling for meal is performed at Reykholar using a five-deck conveyor dryer. Recovery of salts from brines is planned.

W. Burrows [4] described utilization of geothermal energy in Rotoura, New Zealand. The uses of geothermal energy in Rotoura come from over 700 registered geothermal bores. Effluent disposal is accomplished by boreholes with a six-inch casing to a permeable strata. Heat exchangers involving combinations of contraflow units are very efficient and increasing in number. A relatively low output bore can be made to do a large job by means of a storage-type exchanger used on a mixed secondary circuit in conjunction with a time switch. Geothermal control valves presented a real problem until Satchwell M. H. valves were used; however, due to a scarcity of this valve, motorized versions of ball-type valves are now being brought into use. The Forest Research Institute uses geothermal energy for timer drying kilns, space heating and cooling of a laboratory complex. A 2000 foot long transmission line is used to supply fluid to the Institute. The Queen Elizabeth Hospital has 200 beds, outpatient service, and a cerebral palsy unit. The hospital has a physiotherapy wing and a full hydrotherapy wing consisting of two pools. A generous source of geothermal energy is used to supply heat for this hospital.

I. M. Dvorov [5] described the utilization of the earth's thermal energy in the USSR. The USSR has enormous geothermal reserves with 50 to 60 percent of the land mass underlain by hot water suitable for commercial use. These hot water reserves have temperatures from 40 to 200°C, mineralization up to 30 g per liter and exist at depths up to 3500 m. The total reserves have been evaluated at 19.75 million m^3 per day. Geothermal hot water is used for space heating by direct use and in peaking boiler plants. Heat pumps are also used for heating and refrigeration. Vegetable growing in the greenhouse uses geothermal hot water from 35 to 200°C with the most efficient lowest temperature for greenhouses at 35 to 80°C, depending upon the outside temperature. Geothermal waters are regarded as a source of energy and as a source for minerals such as iodine, bromine, lithium, cesium and strontium.

Presently, investigations are being made into the use of geothermal energy for thawing frozen ground for placer mining; extraction of heat from bedrock by fracturing with explosives and injecting cold water to be heated in high temperature gradient areas; heating concentrates at ore mills and moistening air in mines; and for balneological purposes.

R. D. Wilson [6] reported use of geothermal energy in Kawerau, New Zealand. The sites for the integrated newsprint, pulp and timber mills of the Tasman Pulp and Paper Company and Paper Company Limited and the associated town of Kawerau, were selected in 1952 in close proximity to an area of thermal surface activity. Investigation and subsequent drilling in the area produced useable quantities of geothermal steam. The steam-water mixture produced by the geothermal bores is generally separated at the well heads into its two fractions. The steam is piped to the mill and hot water discarded. Geothermal energy is used by Tasman for timber drying, black liquor evaporation, pulp and paper drying and for electric power generation. Recent surveys of the area and an investigation drilling program planned by the Ministry of Works and Development, which was scheduled to commence in 1975, are expected to determine the extent and future development of the Kawerau field. The present energy crisis has placed further emphasis on the important part geothermal energy plays in Tasman's operations.

E. F. Wehlage [7] described geothermal energy's potential for heating and cooling in food processing. Geothermal heat applied to food processing has a potential for relieving part of any strain resulting from crises in energy and food. The term "geo-heat" is applied to simplify reference to process heat derived from geothermal sources. Indication of the available geothermal heat to parallel food processing temperatures is included. Direct production of refrigeration effect, by-passing electric generation, is possible at +4 or -60°C. Technology for food processing is well advanced beyond any equivalent technology for applying geo-heat. More research in several fields will be needed for full utilization of geo-heat to process food wherever such heat potential exists.

A. M. Linton [8] reported innovative geothermal energy uses in agriculture in Rotorua, New Zealand. Geothermal heat has been used for agricultural purposes since the late 14th century at Rotorua. The wells produce both steam and hot water. A good four-inch geothermal bore produces from 10,000,000 to 12,000,000 BTU/hour. About 350 bores are in existence; many heat several residences besides being used for horticulture. The hydrogen sulfide and sulfur dioxide in the fluid and steam aid in controlling fungus diseases. Horticultural crops grown in the warm atmosphere are orchids, carnations, mushrooms, tomatoes, french beans, lettuce and others. Pineapples and bananas are grown in areas where temperatures may fall below -10° Celsius. Alfalfa is processed for protein by using geothermal heat in the processes. Development of the dependable resource is progressing rapidly and, when completed, will aid the country to be more nationally self-sufficient for energy sources.

J. Zoega [9] described the Reykjavik Municipal District Heating System using geothermal energy. The Reykjavik District Heating System uses natural heat resources, found in the city and it's vicinity to heat 11,000 houses, serving some 88,000 inhabitants. The natural hot water used is obtained by drilling in known thermal areas and in areas found to be promising by various geophysical methods. The water used is chemically clean, directly potable and contains only a small amount of dissolved solids. It is also non-corrosive to steel and ordinary black steel pipes are used throughout the system. Load density in the city is low, the average being 20 MW/km^2 and 1.9 MW/km of distribution mains.

The climate in southern Iceland is mild considering latitude, the mean temperature in July being 11°C, and in January is 0.4°C, and the consumption of hot water in January is only two to three times that of July; thus, due to the relatively cold summers and warm winters, the equivalent hours at peak power for natural heat alone are 4500 hours per year. (Load factor 50 percent.) Water meters are used for billing and the cost of heating averages 30 percent of the cost of individual fuel oil boiler heating.

The growth of the city, as well as the supply of neighboring communities having 26,000 inhabitants, will in the near future necessitate exploration and development of thermal areas further from the city where temperatures up to 280°C have been found. This project enables combined production of heat for the district heating system and electricity.

Lund, Culver and Svanevik [10] described the utilization of geothermal energy in Klamath Falls, Oregon. Klamath Falls is located on the Known Geothermal Resource Area (KGRA) which has been used by residents, principally in the form of hot water for space heating, at least since the turn of the century. Approximately 400 shallow depth wells ranging from 27 to 580 meters (90 to 1900 feet) in depth are used to heat approximately 500 structures. This utilization includes the heating of residences, schools, businesses (including a creamery for milk pasteurization), heating swimming pools and melting snow from pavements. Seventy-five locations were selected for detailed study documentation during the summer of 1974.

Well water, which ranges from 30°C (100°F) to 110°C (230°F) has been used directly in heating and drinking water systems. However, present practice is to use down-hole, hair-pin heat exchanger with city water as the circulating fluids. Well water chemistry indicates approximately 800 mg/1 (ppm) dissolved with sodium and sulfate having the highest concentrations. Calcium and potassium concentrations are very low. Some scaling and corrosion does occur on the down-hole heat exchangers (black iron pipe) which is related to the Langelier Saturation Index.

Cost analysis for capital and annual operation costs were presented and compared with alternate forms of energy (electricity, natural gas and fuel oil). For a single residence, at today's costs, heating using geothermal water appears to be somewhat competitive. However, when several structures use the same well, the savings are substantial. District heating, similar to that in operation in Iceland, is being proposed. The average annual energy utilization is only 5.6 megawatts. It is felt that only a small portion of the area's potential is being utilized, with speculation that a high temperature steam area exists below the known shallow reservoir.

W. D. Purvine [11] reported the geothermal energy utilization at Oregon Institute of Technology in Klamath Falls. The Oregon Institute of Technology campus was relocated in 1959 to make maximum use of potential hot water for space heating approximately 440,000 square feet of floor space (40,900 square meters). Based on observations of early morning frost and snow melting, and conversations with local hot water well drillers, six wells were sited along a major fault zone adjacent to the campus. Depending upon the exact location with reference to the fault line three cold and three hot water wells were located at depths from 1200 feet (366 meters) to 1800 feet (550 meters). The cold water wells produced water at 191°F (88°C) with the latter producing up to 750 gallons per minute (2839 liters per minute). The water is piped from the hot water wells and passed through forced air and hot water radiators within the buildings on campus. An average of 2.8 million BTU per hour (0.705 x 10^9 Gcal per hour) with a maximum of 24.8 million BTU per hour (6.26 x 10^9 Gcal per hour) is used for the campus, at considerable savings from the heating of the old campus, using conventional fuels.

Donovan and Richardson [12] reported a feasibility design study for the Boise, Idaho, geothermal space heating demonstration project. Geothermal space heating has been attempted on a modest scale at only two United States localities, the oldest of which is the geothermal heating system in Boise, Idaho, which has served the Warm Springs residential area since 1890. This system, with water at 170°F pumped from two 440-ft. deep wells, at one time served 400 homes and business establishments but presently serves only about 120 homes. These two wells are known as the Old Penitentiary wells and are thought to be drilled intersecting the foothills fault geologic plane.

The above review of background information reveals that non-electric application of geothermal energy and especially that of low temperature water have potential for immediate development and use. When these potential developments are instituted, they will do much to help us solve short-range and long-range energy needs of the nation.

OBJECTIVES

The specific objectives of the present study were as follows:

1. To determine if the geothermal energy source adjacent to the NMSU campus can be utilized for a portion, or all, of the heating, cooling, and electrical needs of the campus.
2. To identify and interrelate the required hardware and energy conveyance and conversion system through parametric evaluation.
3. To integrate the geothermal energy source with existing facilities and/or to conceive an independent energy delivery system.
4. To initiate and outline a study of the environmental impact of the geothermal energy development.
5. To initiate an identification and itemization of the regulatory and institutional impediments to the development of this resource.

SECTION II

GEOTHERMAL RESOURCES ON AND NEAR NMSU LAND

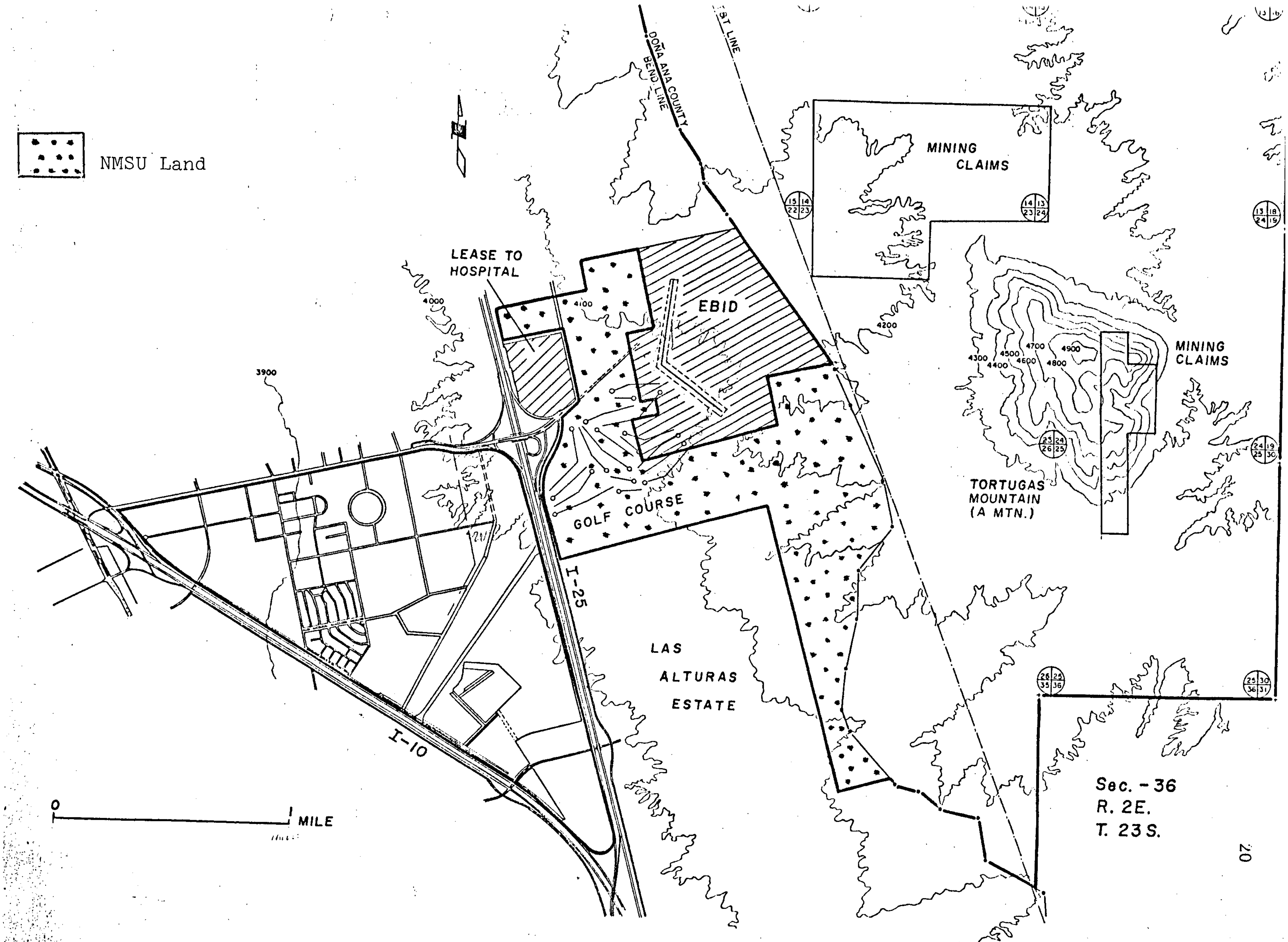
INTRODUCTION

New Mexico State University owns about 1000 acres of land adjacent to the campus at Las Cruces. This land lies east of Interstate Highway 25 and is bounded by Doña Ana County bend line on the east and Las Alturas Estates (a private residential community) to the south (Figure 1). Sections 13, 14, 24, 25 and parts of sections 15, 26, and 35 of Township 23S, Range 2E belong to Federal Government and are managed by the Bureau of Land Management. These sections, excluding the mining claims on and northwest of Tortugas Mountain, are under "withdrawal" for the surface to be used by NMSU for physical and biological research. However, BLM still controls the subsurface water and mineral rights on this land. Section 36 belongs to the State of New Mexico.

The land shown as NMSU land on Figure 1 is completely owned by the university, including subsurface water and mineral rights. In recent years, the university has leased part of its land to the Memorial General Hospital and to the Elephant Butte Irrigation District. These leased lands are so shown on Figure 1.

During nineteen sixties, the Las Alturas Subdivision was beyond the reach of city water and home owners drilled wells for their water supply. Almost all the wells, ranging in depth between 175 ft. to 486 ft., reported finding warm to hot water (35°C-45°C). A deep well was drilled in 1948-49 in the northwest corner of Section 36 (state land). The well (Clary and Ruther No.1, log no. 6862, New Mexico Bureau of Mines and Mineral Resources) was an exploratory oil well and was drilled to a depth of 2573 ft. The log of this well makes no mention of unusual temperatures found - probably

Figure 1. NMSU Campus and University Owned Land East of I-25. The Land Surrounding Tortugas Mountain (Section 13, 14, 24, 25 and Part of Section 15, 22, 23, 26 and 35) is Federal Land on Withdrawal to NMSU by The Bureau of Land Management, for surface research only.



NMSU Land
LEASE TO HOSPITAL
DOÑA ANA COUNTY BEND LINE
MINING CLAIMS
EBID
GOLF COURSE
MINING CLAIMS
TORTUGAS MOUNTAIN (A MTN.)
I-25
I-10
LAS ALTURAS ESTATE
4000
4100
3900
4200
4300
4400
4500
4600
4700
4800
4900
0
1 MILE
Sec. - 36
R. 2E.
T. 23 S.

Figure 1

because in those days, finding hot water instead of oil must have been embarrassing. However, there are some eyewitness accounts of the well having encountered "steam and hot water." The locations of all the hot wells known in the area are shown in Figure 2. The presence of warm to hot water at shallow depths indicates the possible presence of significant geothermal resource in this area.

GEOLOGICAL SETTING

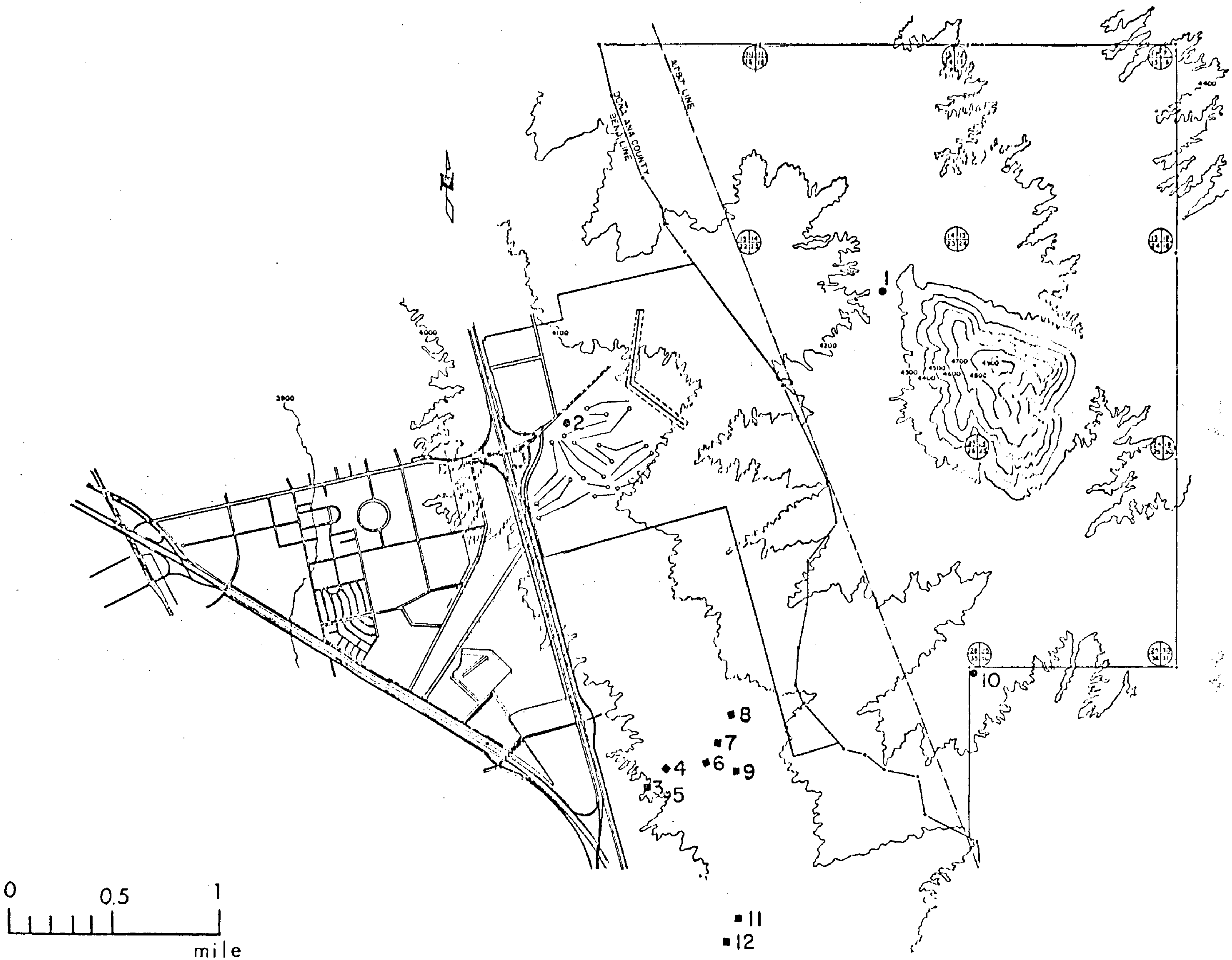
The area under investigation lies on the eastern edge of the Rio Grande Valley and just west of Tortugas Mountain. It lies in the Mexican highland section of the basin and range physiographic province. Figures 3 and 4 show the physiographic and regional geological setting of the area, respectively.

On the Tortugas Mountain, hueco limestone of Permian age emerges from Santa Fe group and recent alluvium. Similar rocks are exposed at Bishop Cap Mountain and near the Organ Mountains. There are thick piles of silicic volcanic rocks exposed in the southern half of the Dona Ana Mountains and in the southern Organ range. These consist of ash-flow tuff sequence and associated rhyolitic to monzonitic intrusive rocks. In the Dona Ana mountain area, these rocks have been dated to be 33 to 37 million years old, according to K-Ar dating.

Figure 5 shows the late tertiary fault patterns in the Las Cruces and surrounding area. The Las Alturas geothermal area lies between the valley fault and the fault that flanks the east side of the Tortugas mountains.

On the basis of thick piles of a really limited occurrence of silicic volcanics of oligocene age ($\sim$37 m.y.), the tertiary fault pattern interpreted from field studies, gravity anomaly maps, and other tectonic features, Seager [13,14] has postulated a cauldron mode of tectonic origin for

Figure 2. Location of Hot Wells in Las Alturas and Neighboring Area (See Table 1 for Description).



LOCATION OF HOT WELLS ON AND NEAR N.M.S.U. LAND

Figure 2

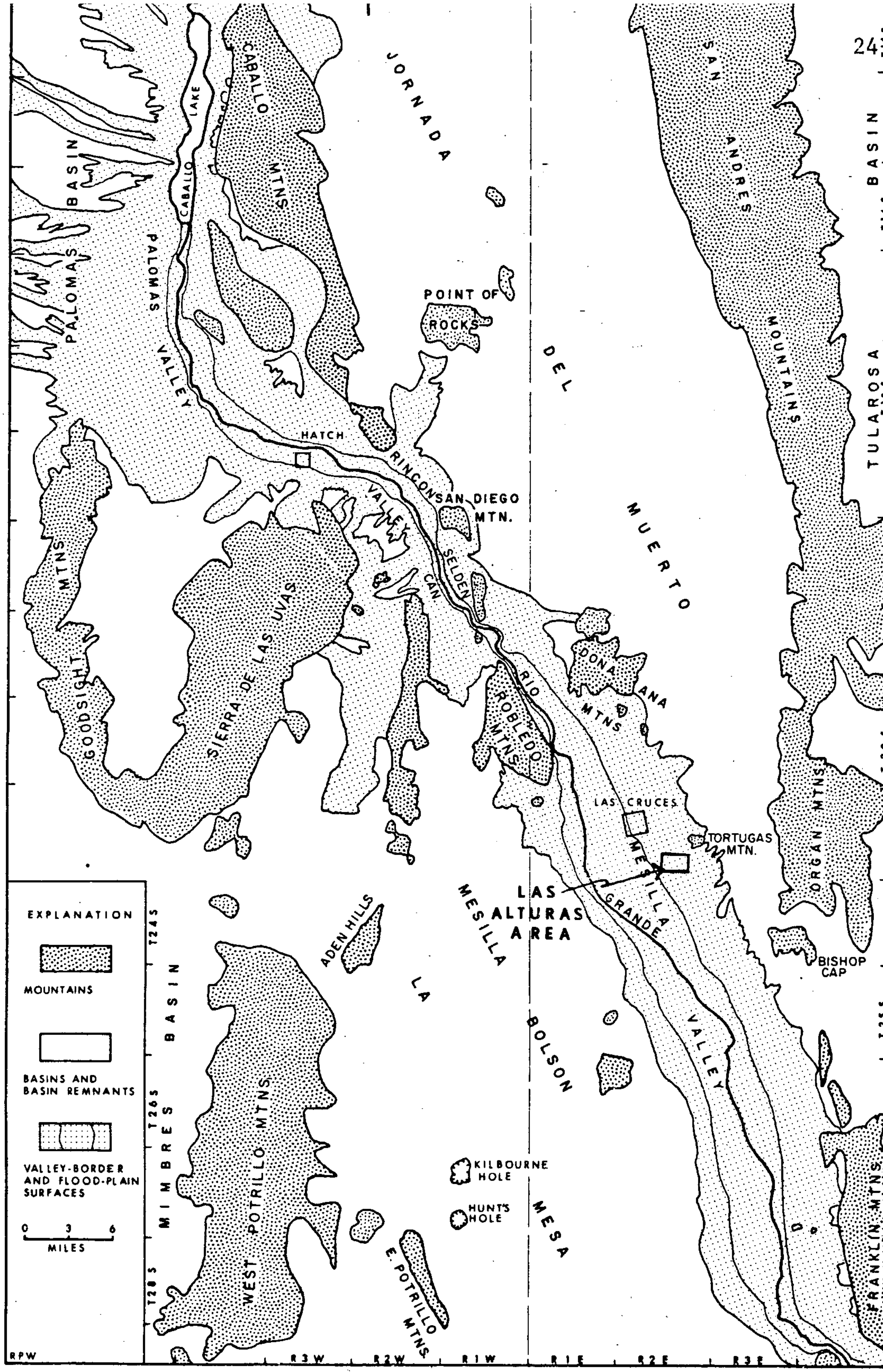


Figure 3. Physiographic Map of Las Alturas and Surrounding Area [23].

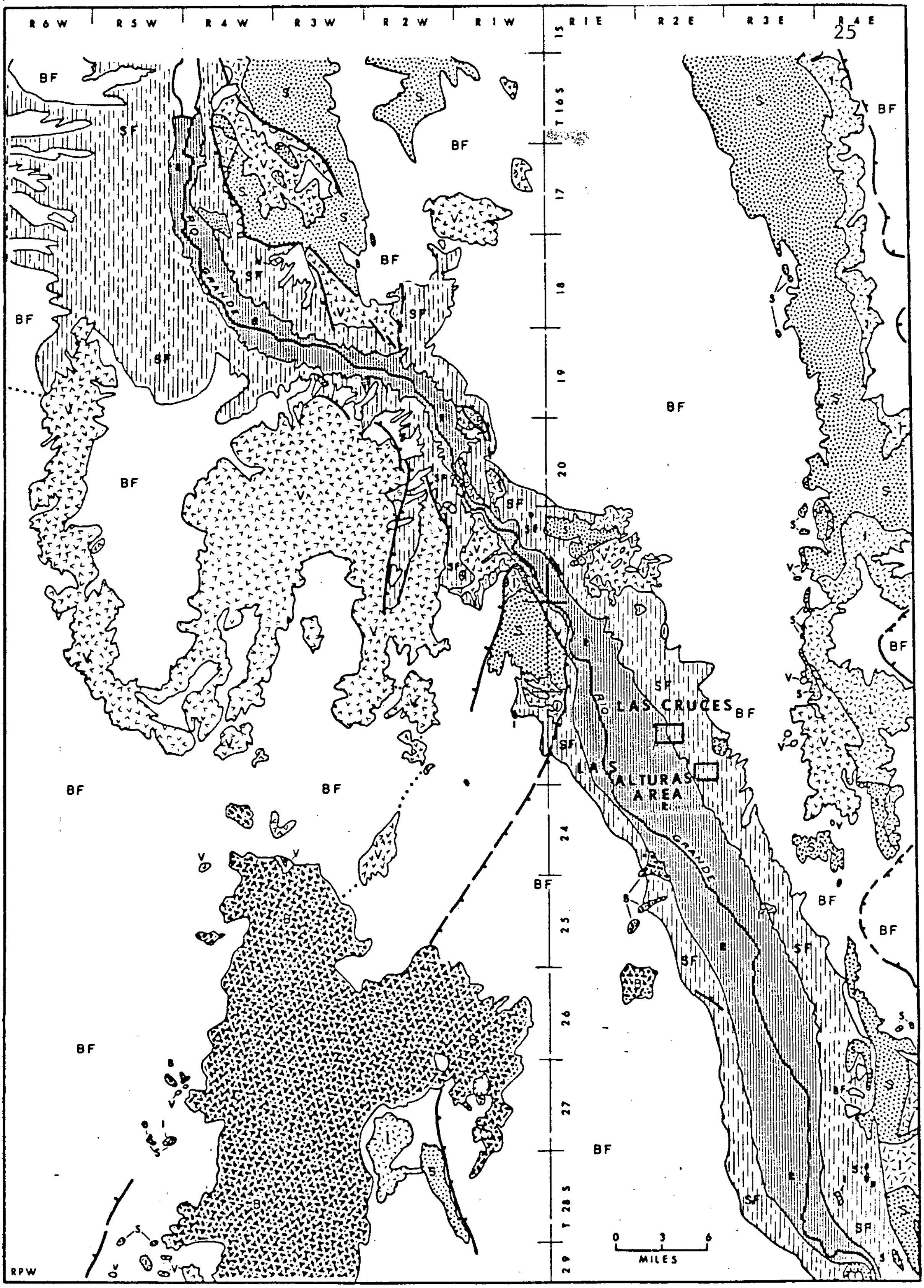


Figure 4. Generalized Geologic Map of Las Alturas and Surrounding Area [23].

R	Valley-fill alluvium; Lake Quaternary; clay to gravel, less than 80 feet thick.
B	Olivine basalt flows and volcanic cones; Quaternary, generally post date the Santa Fe Group.
BF	Basin-fill surface. Santa Fe Group, with discontinuous overlay (generally less than 25 feet thick) of younger alluvial, eolian and minor lacustrine deposits.
SF	Santa Fe Group basin fill; Miocene to Middle-Pleistocene; clay to gravel, locally as much as 4,000 feet thick. Also discontinuous overlay (generally less than 100 feet thick) younger valley slope deposits.
V	Volcanic rocks, and associated clastic sedimentary rocks, undifferentiated; Middle Tertiary.
S	Sedimentary rocks, undifferentiated; Paleozoic, Cretaceous and Early Tertiary.
I	Intrusive rocks, undifferentiated, and associated metamorphics; Precambrian and Tertiary.
......	Santa Fe–Gila Group Boundary.
─┬─┬─	Faults involving significant displacements of Basin Fill.

GEOLOGIC MAP LEGEND
For Figure 4

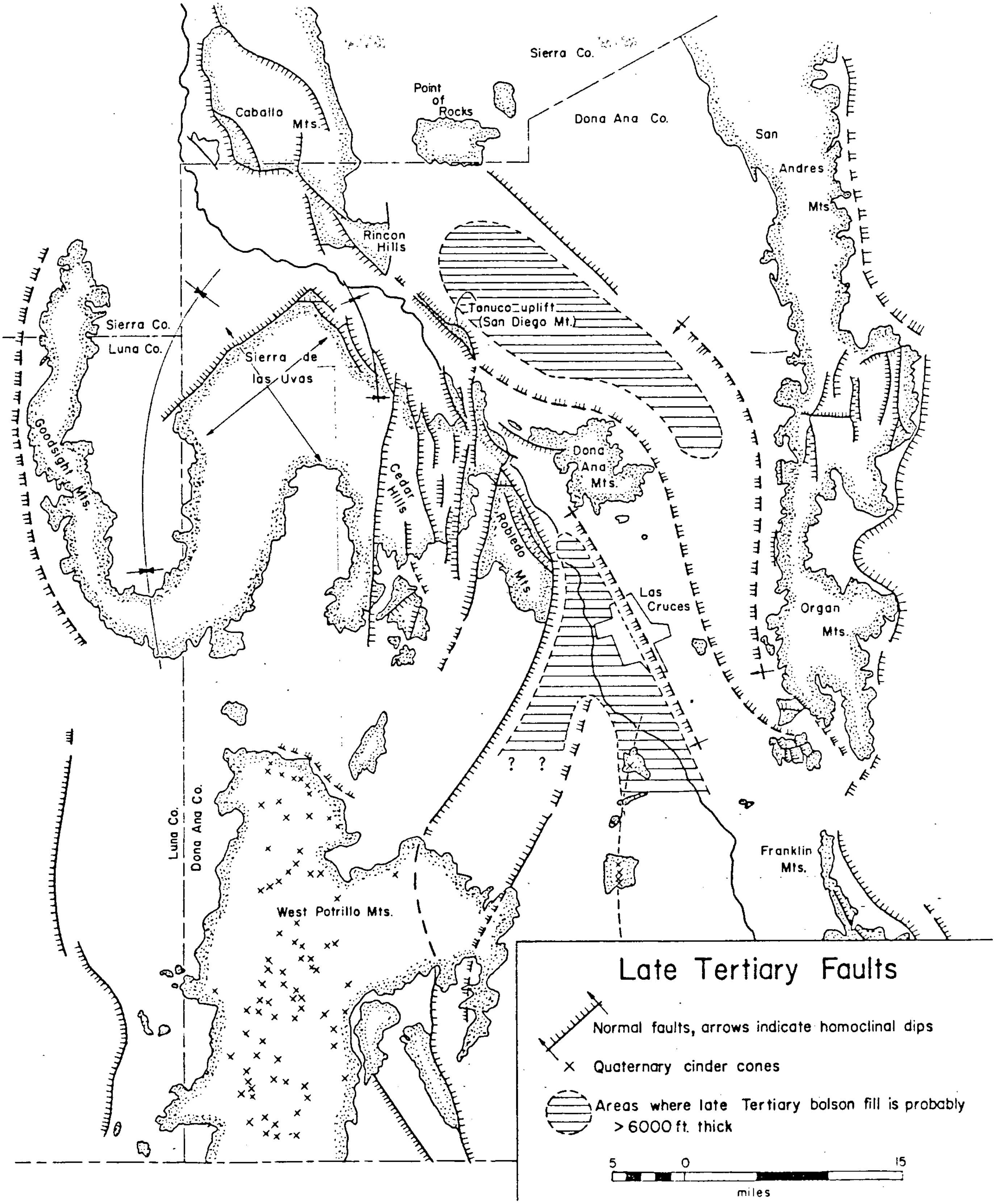


Figure 5. Late Tertiary Faults in Dona Ana County - Confirmed and Postulated by Seager [13].

the Dona Ana and Organ Mountain areas (Figure 6). According to this interpretation, the structurally high Paleozoic rocks exposed at Tortugas Mountain (just east of Las Alturas area) may represent cauldron walls, with the lowlands between these rocks and the Organ volcanics a cauldron moat. According to Seager's interpretation, gravity maps between Bishop Cap and Tortugas Mountain (Figure 7) support the idea of an arc-shaped buried cauldron rim facing the southern Organ range.

Another interpretation of the geological setting of this area is based upon the existence of a chain of intrarift horsts which bound the Jornada basin north of Tortugas mountains. Evidence of this buried "bedrock high" is provided by the exposed Dona Ana mountains, Goat Mountain and the Tortugas Mountain itself, as well as by the existence of a narrow, linear, buried ridge north of Tortugas Mountain interpreted from the electrical resistivity survey conducted by the U.S. Geological Survey (C. Wilson, Personal Communication, 1977, [15]).

The subsurface geology of the area consists of valley fill alluvium of late Quaternary and recent age which extends to approximately 80 ft. depth from the surface. Below it lies the Santa Fe group basin fill which may extend to a depth of 4000 ft. below the surface. Weathered sedimentary rocks of Upper Paleozoic Age may be encountered in this area at a depth of 1000-2000 ft.

HOT WELLS

A wildcat exploration well for oil was drilled in the northwest corner of Section 36 T.23S, R2E in 1948-49. The well, known as Clary and Ruther State No. 1, was drilled to a depth of 2573 ft. New Mexico Bureau of Mines and Mineral Resources has on record a driller's log of this well, which indicates that the well encountered rocks of Pennsylvanian Age at 1526 ft.

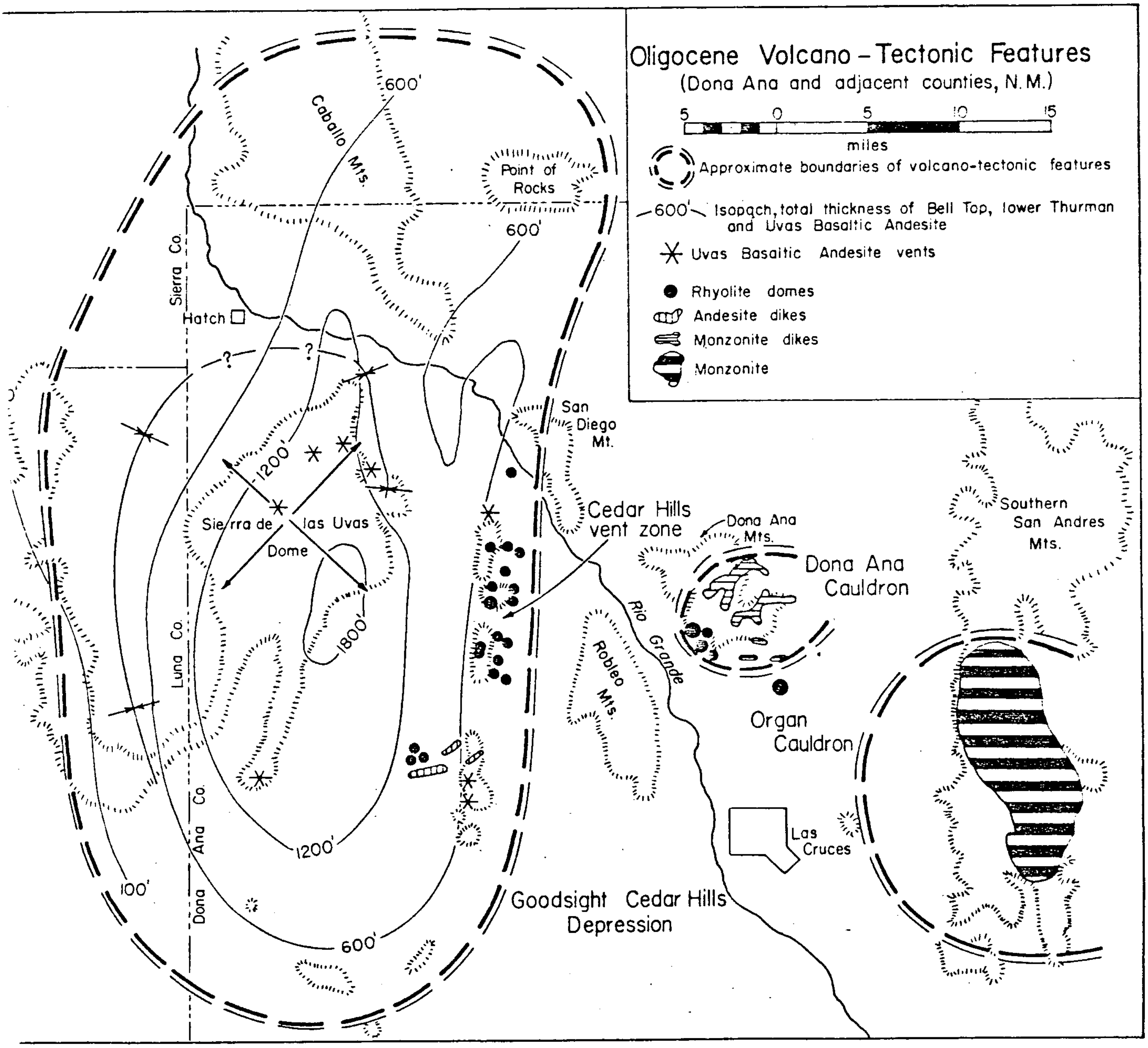


Figure 6. Oligocene Volcano - Tectonic Features of Dona Ana and Adjacent Counties, NM, [13].

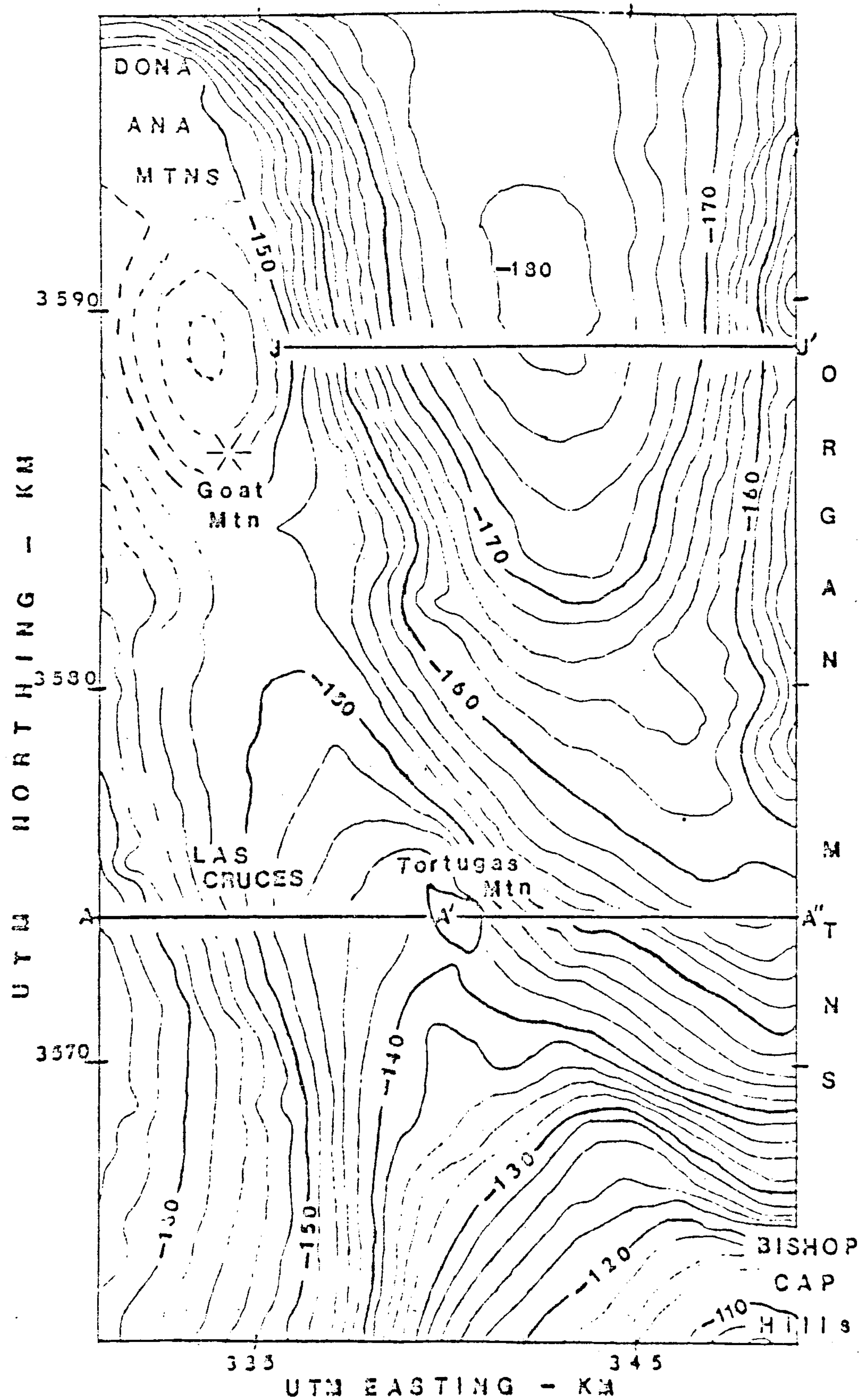


Figure 7. Bouger Anomal Gravity Map of Las Cruces area, NM, [24].

depth and Mississippian rocks at 2573 ft., but makes no mention of hot water or high temperatures encountered. The well was plugged in 1953 and according to the report on plugging, filed with the New Mexico Oil Conservation Commission, the well has been plugged with cement at the top, at 400 ft. and at 555 ft.

Since the well was drilled for oil, the operators did not publicize their encountering hot water in the well at relatively shallow depths. In the local newspaper (Las Cruces Sun News, November 1948-April 49) reports of that period there is no mention of the well encountering hot water. However, from the information obtained from several reliable sources, there appears to be little doubt that hot water, at relatively shallow depths, was encountered in that well.

According to Mr. Floyd Johnson, an old-time well driller of Las Cruces, "the Clary and Ruther well definitely found very hot water mixed with gases. The water was excessively hot. The tools got so hot you couldn't touch them."

Mr. Johnson referred to Mr. John Black, who now lives in Monahan, Texas. Mr. Black used to work with Mr. Johnson until 1948 when he started working with Clary and Ruther's team and left with them to drill oil wells in Texas. In a telephone conversation on August 3, 1977, Mr. Black stated that he left Las Cruces when the well was only about 700 ft. deep and they had already found plenty of hot water. According to him, "the water was 180°F, it was scalding hot. We bailed it out for 24 hours and the temperature did not go down."

During the investigation of this well, it was possible to locate Mr. Richard Ruther, son of the late Mr. L. B. Ruther, who was one of the two original partners in the drilling of this well. Mr. Richard Ruther was a young man of 20 years of age when he came with his father and worked on the well. Mr. Richard Ruther now lives in Clovis, New Mexico, and, in a telephone conversation on August 8, 1977, he had this to say about the well, "At 710 ft., the water was hot enough to boil an egg."

Dr. Jack A. Soules was one of the persons responsible for the development of Las Alturas Estates. He was a Professor of Physics at NMSU in the 1960's and is now a Dean at Cleveland State University in Cleveland, Ohio. In a telephone conversation in May 1977, Dr. Soules stated that an old-time resident of Las Cruces and a well-trained engineer, the late Mr. William T. Bixler, told him (Dr. Soules) in 1967 that they had found "hot water and steam" in the Clary and Ruther well.

According to the recollection of Mr. James Field, emeritus professor of Mechanical Engineering at NMSU, who supervised university wells for the Physical Plant Department, hot water was found in Clary and Ruther well and it was 157°F (70°C) "at fairly shallow depths."

Mr. Willy Presiado, who was in charge of maintenance at the Physical Plant of NMSU for 50 years before retiring, also remembers reports of hot water encountered in the Clary and Ruther well.

There are several other wells in the area which are reported to have encountered hot water ranging in temperature from 93°F (34°C) to 115°F (46°C) at depths between 175 ft. to about 400 ft. The location of these wells is shown in Figure 2. The most concentrated drilling for water was done in the Las Alturas area in years 1967 and later. The hottest well reported in the area is that drilled by Mr. Emmett Nations. Mr. Nations now lives in Albuquerque. In a telephone conversation on August 3, 1977, Mr. Nations informed us that hot water at 45°C was encountered at a depth of approximately 200 ft. Soon after drilling, the well was pumped at 30 gallons per minute for 48 hours without noticing any change in temperature or flow.

Mr. James Field also informed us of a hot well that was drilled near the Physical Science Laboratory (PSL) antenna towers near Tortugas Mountain (Well No. 1, Figure 2). The drilling contractor for the well was Hardrock Schieffer. Mr. Schieffer told us that the well, drilled in early 1960's, was drilled to a depth of over 200 ft. and had not yet encountered hot water. However, "the well was very hot and the tools that came up from the bottom of the hole were too hot to hold in bare hands."

Several other hot wells have been reported in this area. The southernmost one reported for this area was drilled in March 1975 at the property of Charles Jordan. This well also has a temperature of 115°F (46°C). All these wells are shown in Figure 2 and described in Table 1.

HEAT FLOW AND GEOTHERMAL GRADIENTS

Las Cruces and surrounding areas have reported regional heat flow values of 2.1 to 2.8 HFU (Decker, et. al, [16], which makes it a good geothermal potential area. Recent temperature measurements in existing wells in the Las Alturas area are recorded in Table 2. According to this information, the highest thermal gradient recorded in this area is reported from Emmett Nations' (present owner is Huddleston) well. At a depth of 20 to 25 meters, a gradient of 412°C per km was recorded. This is an exceptionally high value of geothermal gradient and provides yet another proof of the geothermal potential of this area.

GEOTHERMAL GEOCHEMISTRY

Figures 8 and 9 show estimated maximum temperatures of geothermal fluids in the Las Cruces area based on Na-K-Ca and SiO_2 geothermometry respectively. In the Las Alturas area, the maximum temperatures inferred

Table 1

SUMMARY OF DATA ON WELLS IN LAS ALTURAS AND SURROUNDING AREA
(Numbering of wells same as Figure 2)

Well No.	Year of Drilling	Owner and Location (Past and Present)	Max. Temperature (°C)	Water Level (ft.)	Total Depth (ft.)	Total Dissolved Solids PPM	Remarks
1	1960	NMSU Near Antenna Towers NW Tortugas Mountains	Hot	Dry	200	-	Dry; hot well, "Tools too hot to hold in hand
2	1961-62	NMSU Golf Course	24	-	630	1548	Abandoned due to high salinity
3	1957	Soules Las Alturas Estate	25	161	296	-	See Table 2 thermal gradient
4	1963	L. R. Evans	Hot	174	332	-	
5	1964	Wm. Evans/Partridge	Hot	-	256	-	
6	1964	Rowan	36.7	190-200	330	-	
7	1964	White/Cutcher	34	190	311	-	
8	1964	Nations/Huddleston	45	240	335	1960	
9	1964	Husand/Kinzer	42.5	180	348	520	
10	1948-49	Clary & Ruther State No. 1	Hot	526	2573	-	See Text and Figure 2
11	1975	Charles Jordan	46	200	330	-	4" casing being used for drink-ing water
12	1966-69	Wayne Johnson	21	165	280	Potable	4" PVC being used for domestic purposed on Trailer Park 2000 gallons per day from two wells
13	-	Gordon Ewing (Las Alturas)	30	-	342	533	Not shown on Figure 2
14	-	Mullins (Las Alturas)	27.5	-	350	520	Not shown in Figure 2
15	1956	H. P. Tellyer (Las Alturas)	36.5	-	486	650	Not shown on Figure 2

TABLE 2

TEMPERATURE MEASUREMENTS IN LAS ALTURAS WELLS

WELL NO.: 3 *DATE:* June 8, 1977

TOP OF PIPE FROM GND. SURFACE 2 1/2 ft. below *PIPE I.D.* 6"

RECORDED BY Kelley/Stewart *CABLE RES.* 0.658 *LEAK* 0

DEPTH ZERO POINT Top of Casing *TIME* 13:30

REMARKS Open well in brick housing with roof, David Soules Res.

DEPTH (m)	*FIELD RESIST.*	*TEMP °C*	*GRAD. °C/5m*	*GRAD. °C/Km*	*REMARKS*
10	100.20	21.56	-	-	Slow Drift
15	99.40	21.78	.22	44	" "
20	98.61	21.99	.21	42	" "
25	97.82	22.23	.24	48	" " Cable .0665
30	97.08	22.44	.21	42	" "
35	96.31	22.66	.22	44	" "
40	95.38	22.93	.27	54	" "
45	94.14	23.30	.37	74	" "
50	92.84	23.68	.38	76	" "
55	92.57	23.76	.08	16	WATER
60	92.16	23.89	.13	26	
65	91.60	24.05	.16	32	
70	91.00	24.21	.16	32	
75	90.59	24.36	.15	30	
80	90.16	24.49	.13	26	80 < Bottom < 85
85	90.15	24.50	.01	-	

TABLE 2 CONTINUED

TEMPERATURE MEASUREMENTS IN LAS ALTURAS WELLS

WELL NO.: 8 *DATE:* June 21, 1977

TOP OF PIPE FROM GND. SURFACE 8" Below *PIPE I.D.* 4"

RECORDED BY Kelley, Rybarczyk *CABLE RES.* .0683 *LEAK* 0

DEPTH ZERO POINT Top of Pipe *TIME* 11:00

REMARKS Nations/Huddleston Res. Pum in well ~ 1" clearance between pump & casing.

DEPTH (m)	*FIELD RESIST.*	*TEMP °C*	*GRAD. °C/5m*	*GRAD. °C/Km*	*REMARKS*
10	96.45	22.62	-	-	slowly drifting
15	90.78	24.31	1.69	338	" "
20	84.22	26.37	2.06	412	" "
25	78.65	28.23	1.86	372	" "
30	73.36	30.12	1.89	378	" "
35	68.99	31.78	1.66	332	" "
40	65.04	33.37	1.59	318	" "
45	61.52	34.86	1.49	298	" "
50	58.38	36.27	1.41	282	" "
55	55.40	37.67	1.40	280	" "
60	52.80	38.95	1.28	256	" " water
65	50.28	40.26	1.31	262	" "
70	49.28	40.80	.54	108	
75	48.34	41.32	.52	104	
80	48.16	41.42	.10	20	75m < Bottom < 80m
					41.42°C = 106.6° F

TABLE 2 CONTINUED

TEMPERATURE MEASUREMENTS IN LAS ALTURAS WELLS

WELL NO.: 9 *DATE:* June 27, 1977

TOP OF PIPE FROM GND. SURFACE 2 ft. below ground *PIPE I.D.* 4"

RECORDED BY Kelly/Alexander *CABLE RES.* .0658 *LEAK* 0

DEPTH ZERO POINT Top of Discharge Pipe *TIME* 10:30

REMARKS Husand/Grant Kinzer well. Located in concrete block well house

DEPTH (m)	*FIELD RESIST.*	*TEMP °C*	*GRAD. °C/5m*	*GRAD. °C/Km*	*REMARKS*
10	95.80	22.81	-	-	slow drift
15	91.30	24.14	1.33	266	slow drift
20	86.85	25.52	1.38	276	" "
25	81.60	27.23	1.71	342	" "
30	78.38	28.32	1.09	218	" "
35	73.60	30.03	1.71	342	" "
40	70.25	31.29	1.26	232	slow drift
45	65.95	32.99	1.60	320	" "
50	61.70	34.78	1.79	358	" "
55	58.82	36.06	1.28	256	" "
60	35.55	37.59	1.53	306	" "
65	53.96	38.37	.78	156	Water
70	52.54	39.09	.72	144	
75	51.13	39.81	.72	144	
80	49.82	40.51	.70	140	
85	48.68	41.12	.61	122	
90	47.74	41.64	.52	104	
95	46.98	42.07	.43	86	
100	46.80	42.18	.11	22	Bottom 9 > m

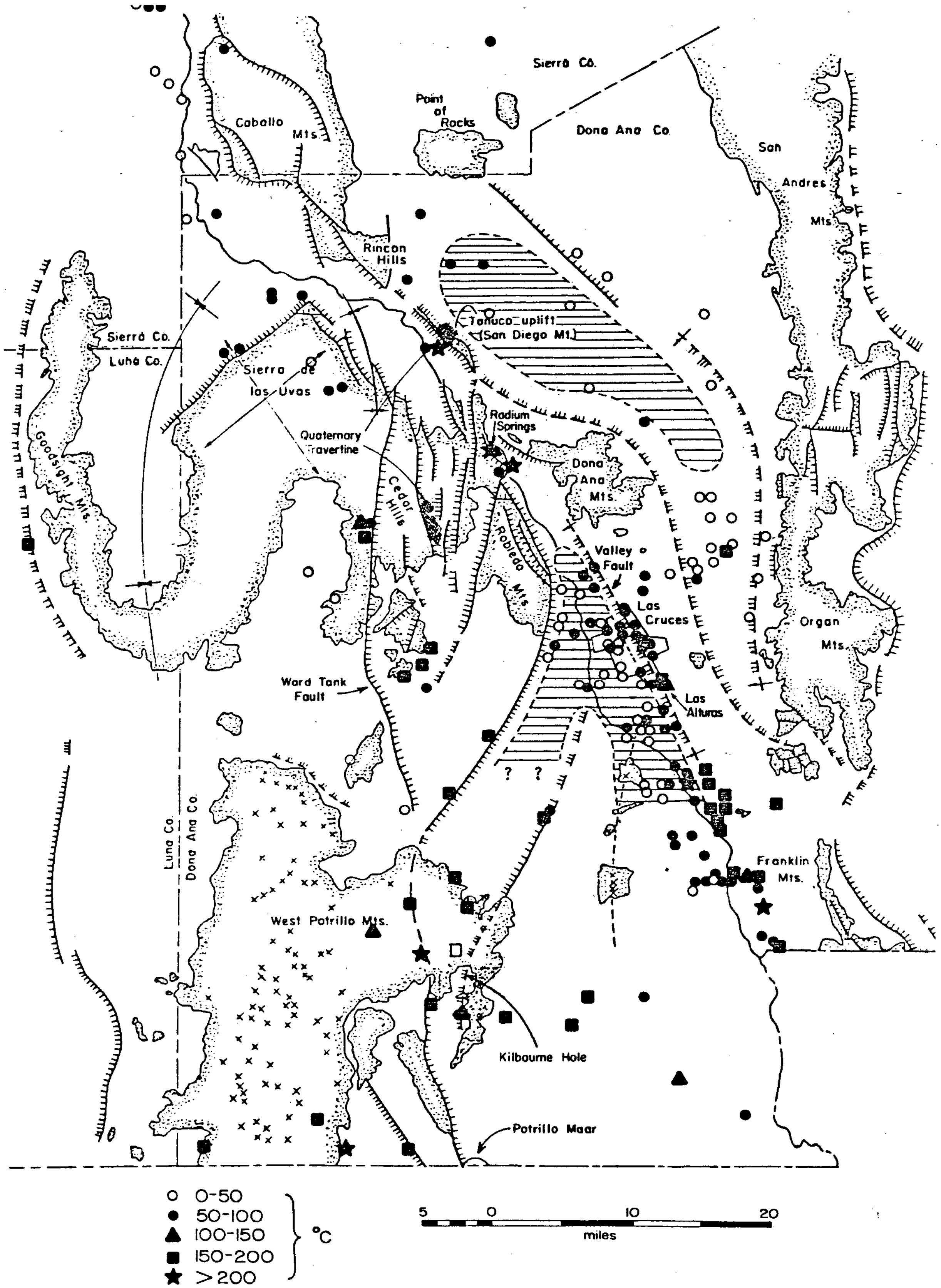


Figure 8. Estimated Base Temperatures Determined by Na-K Ca Geothermometry [25].

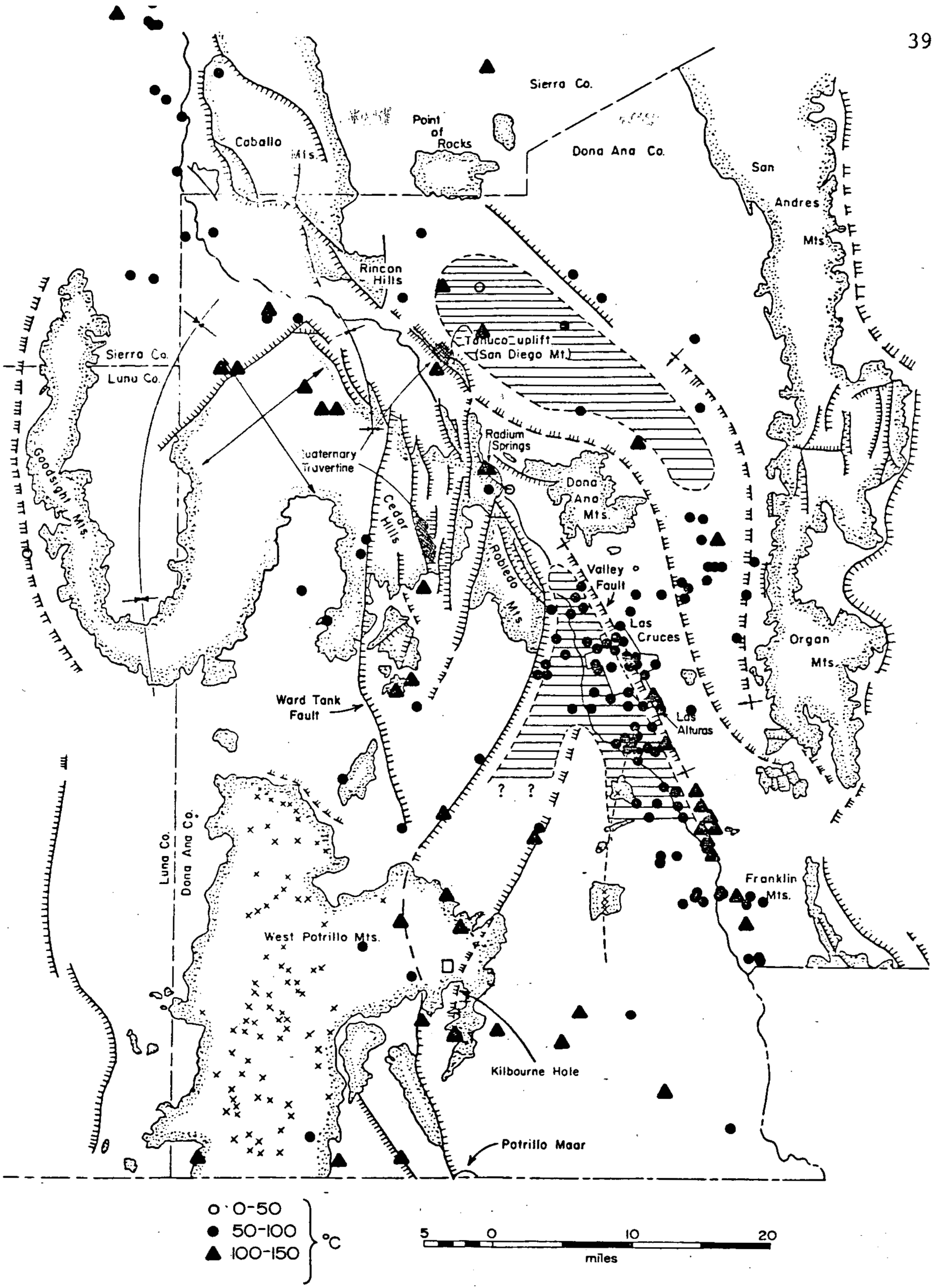


Figure 9. Estimated Base Temperatures Determined by Silica Geothermometry [25].

on this basis are 109°C for silica and 179°C for Na-K-Ca. The geochemically determined high temperature closely coincides with the inferred valley fault and the actually encountered hot water in wells and in the well-known hot springs known as Radium Springs. It appears that the postulated valley fault or some other structural feature parallel to it acts as a conduit for the rise of hot water from depth. There is a rapid decrease of geochemically estimated temperatures away from the fault where, presumably, the thermal water mixes with the cold groundwater.

ELECTRICAL RESISTIVITY SURVEYS

The U.S. Geological Survey has recently published results of their electrical resistivity work in the Las Cruces area (Jackson, [17]). One of the lines of soundings runs parallel and very close to Highway 70 on the east side of Mesilla Valley. The interpretation of resistivity data along this profile matches very well with the known bedrock depth from well records. A resistivity profile between Highway 70 and the Tortugas Mountain also detected a shallow depth to "electrical basement." The USGA Survey did not include a profile in the Las Alturas area. However, a profile located 5 km to the southeast of the Las Alturas hot wells detected a probable 200 meter thick low resistivity layer at an approximate depth of 300 meters.

Figure 10 shows the locations of north and south dipole-dipole soundings of Jiracek and Gerety [18] and Smith [19]. Figures 11 and 12 show the interpretation of dipole-dipole electric resistivity soundings along these lines. Jiracek has suggested "an extension of the Tortugas Mountain block south-southwestward in a horst-like fashion" on the basis of these interpretations. The steep gradients in apparent resis-

Figure 10. Locations of North and South Dipole-Dipole Soundings [19].

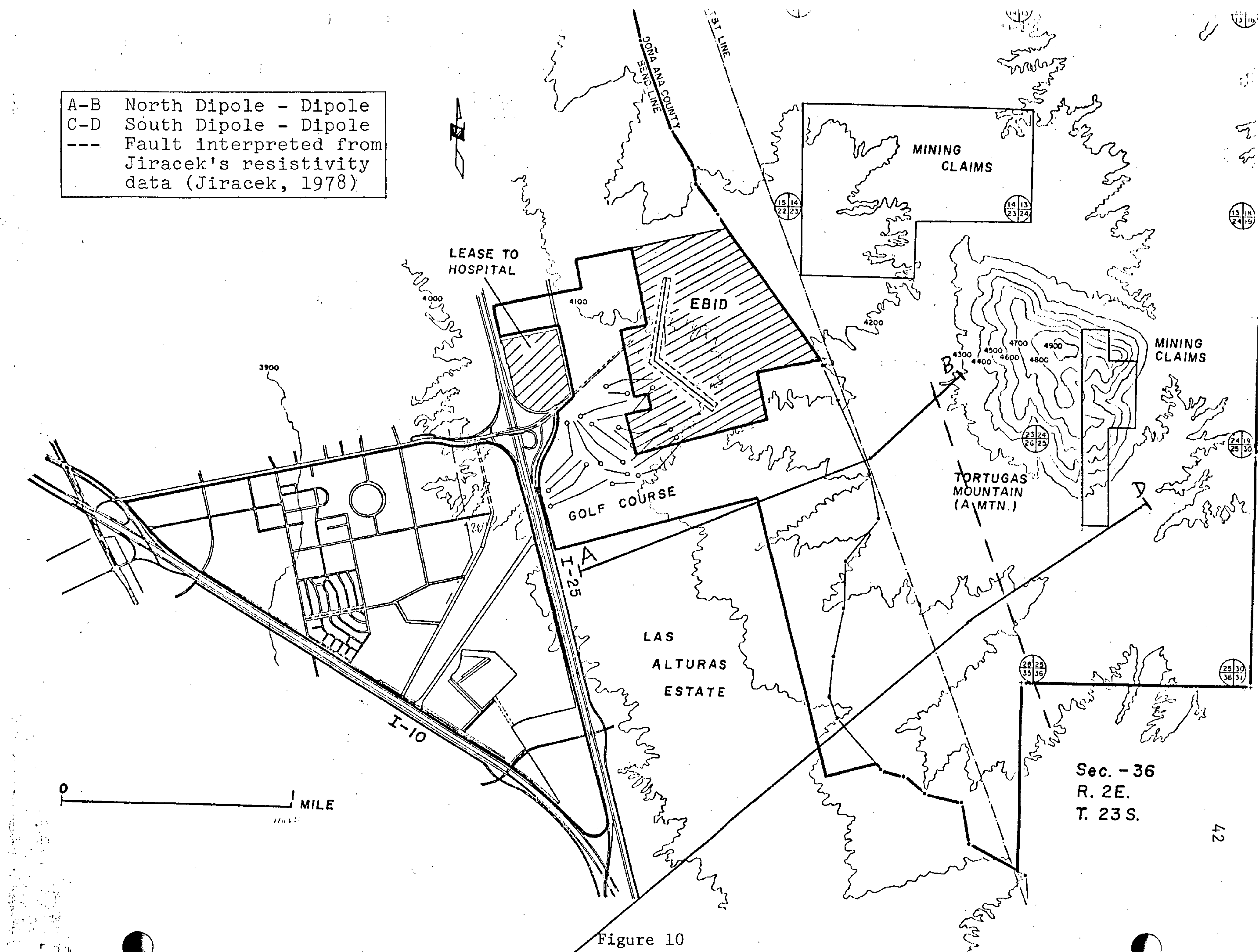
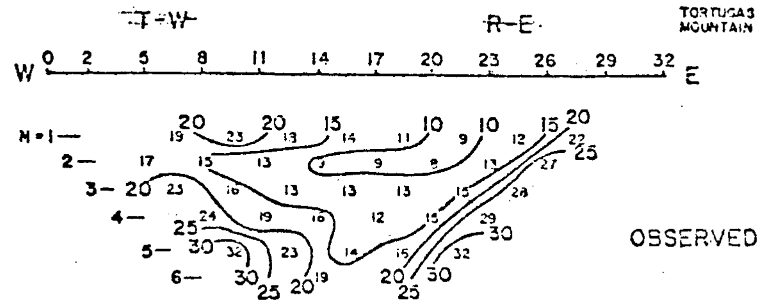

A-B North Dipole - Dipole
C-D South Dipole - Dipole
--- Fault interpreted from Jiracek's resistivity data (Jiracek, 1978)
DOÑA ANA COUNTY
BEND LINE
MINING CLAIMS
LEASE TO HOSPITAL
EBID
4000
4100
4200
3900
4300
4400
4500
4600
4700
4800
4900
MINING CLAIMS
B
A
C
D
GOLF COURSE
TORTUGAS MOUNTAIN (A MTN.)
I-25
LAS ALTURAS ESTATE
I-10
0
1 MILE
Sec. - 36
R. 2E.
T. 23 S.

Figure 10

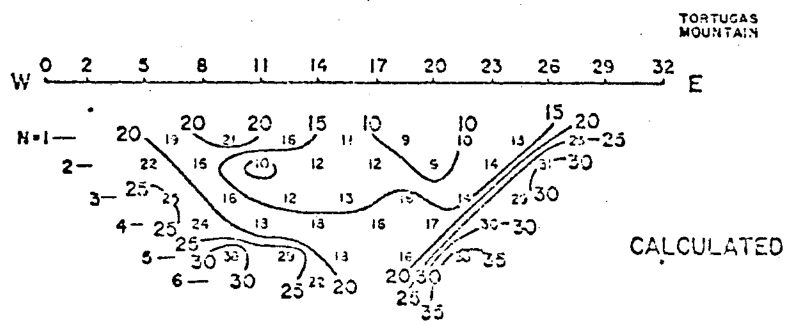
Figure 11. Observed and Calculated North Dipole-Dipole Pseudosections with Resistivity Model at Las Alturas [18].

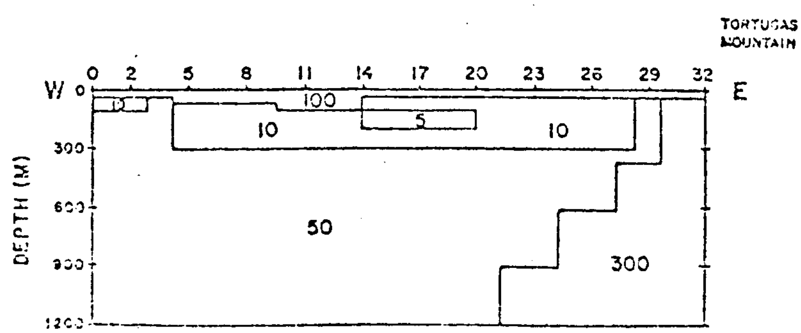


LAS ALTURAS-NORTH
DIPOLE-DIPOLE PSEUDOSECTIONS

X=300M, ρ_a IN OHM-M, C.I.=5 OHM-M

SCALE : 0 600 1200 M





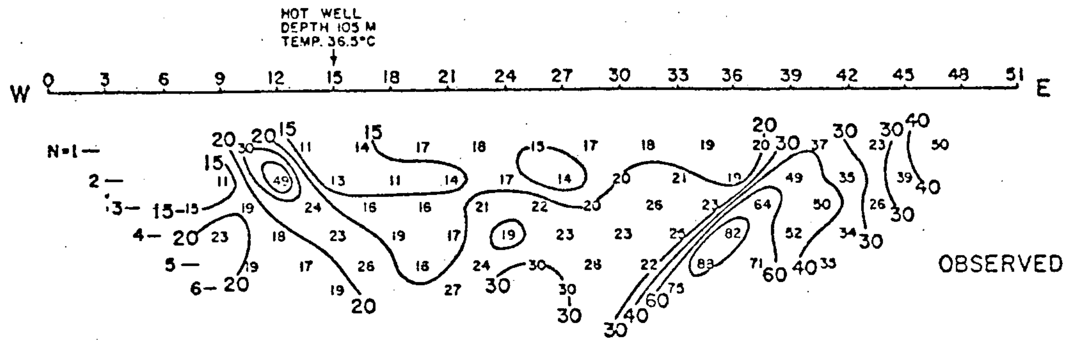
LAS ALTURAS-NORTH
CALCULATED RESISTIVITY MODEL

RESISTIVITY IN OHM-M

SCALE : 0 600 1200 M

Figure 11

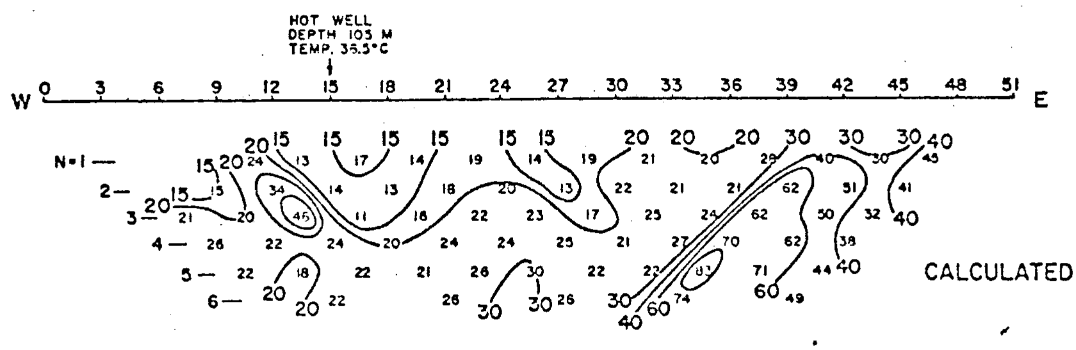
Figure 12. Observed and Calculated South Dipole-Diple Pseudosections with Resistivity Model at Las Alturas [18].

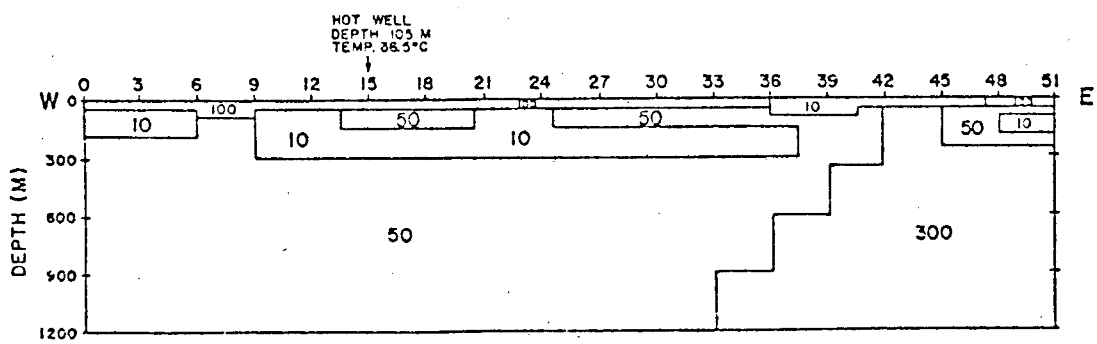


LAS ALTURAS–SOUTH
DIPOLE-DIPOLE PSEUDOSECTIONS

X = 300 M, ρ_a IN OHM-M

SCALE : 0 600 1200 M





LAS ALTURAS–SOUTH
CALCULATED RESISTIVITY MODEL

RESISTIVITY IN OHM-M

SCALE : 0 600 1200 M

Figure 12

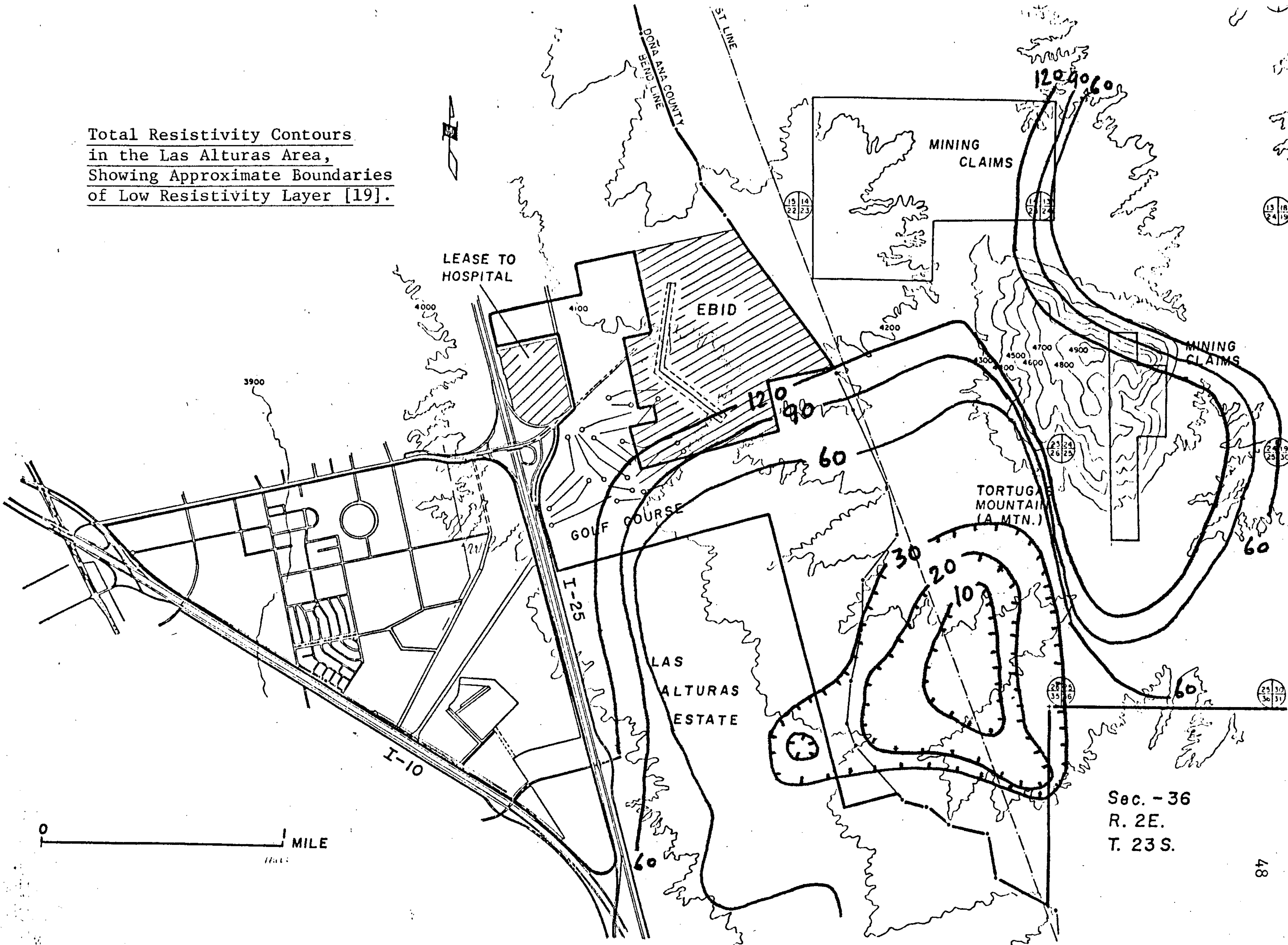
tivity suggest the location of a high-angle fault. Joining the location of the fault (extended to the surface), one obtains an approximate surface alignment of this fault. This is also shown on Figure 10. It appears likely that this fault may be the conduit for bringing the deeply circulated thermal water to a near-surface aquifer. Figure 13 shows the approximate lateral extent of the low resistivity layer.

SHALLOW THERMAL SURVEY

Experience at other locations (Chaturvedi, [20]; Thompson, [21]) has shown that it is possible to locate regions of thermal anomaly in a geothermal area by temperature measurements at 1 meter depth. Even though the distance to hot water is at least 200 ft., the soil overlying the region of highest temperature shows slightly higher temperature than the surrounding area. Presumably, the high temperature region is where hot water ascends from depth.

The least expensive and quickest method of possibly isolating a thermal anomaly is by mounting a thermistor at the tip of a steel rod and by inserting this rod in the ground where temperature is to be measured. In the Las Alturas area, this was not possible due to the lack of moisture and the coarseness of desert sand which made the penetrability of the soil extremely low. Holes, therefore, were drilled using a post hole driller mounted on a tractor and the thermistors were left in place underground for approximately 20 hours. Each thermistor was calibrated and resistance vs. temperature tables were generated for each thermistor.

The raw data from the shallow thermal survey is shown in Figure 13. The thermal survey was started in the Las Alturas hot wells area by laying the observation points on a grid pattern with points about 250 ft. apart from each other. The survey was then extended to cover the area shown in



Total Resistivity Contours in the Las Alturas Area, Showing Approximate Boundaries of Low Resistivity Layer [19].

Figure 13

Figure 14. Five control holes scattered throughout this area monitored the diurnal and seasonal drift. All the readings were corrected for these changes.

Figures 15, 16 and 17 isolate the data to show high and low regions. The limiting sets of values, viz. 31.1°C and 29.3°C; 31.3°C, and 29.1°C; nd 31.6°C and 28.8°C were chosen from the standard normal distribution procedure. It is clear from these figures that the high temperatures at shallow depths are encountered about 2 miles southeast of the intersection of University Avenue and Highway I-25. In addition, high temperatures were recorded on the southwestern corner of Las Alturas Estates. It is to be noted that relatively low temperatures were recorded in the area surrounding the hottest (45°C) well (See Figure 2, Well No. 8 and Table 1). This probably indicates that the hottest well does not necessarily represent the center of thermal anomaly. Well no. 8 (Table 1) is the deepest well of all the wells in Las Alturas and may have reached closest to the geothermal aquifer.

More shallow thermal measurement points in the vicinity of Tortugas Mountain may locate the possible zone of ascending hot water.

QUALITY OF GEOTHERMAL WATER

Table 1 shows the total dissolved solids in waters of different wells in the Las Alturas area. The minimum T.D.S. is 520 PPM and the maximum is 1960 PPM. The water of highest salinity (Well No. 8) is also the hottest water in the area and best approximates the salinity of geothermal fluid before it mixes with near surface cold ground water. For design considerations, a salinity of 2000-2500 PPM for geothermal fluid will be a reasonable estimate.

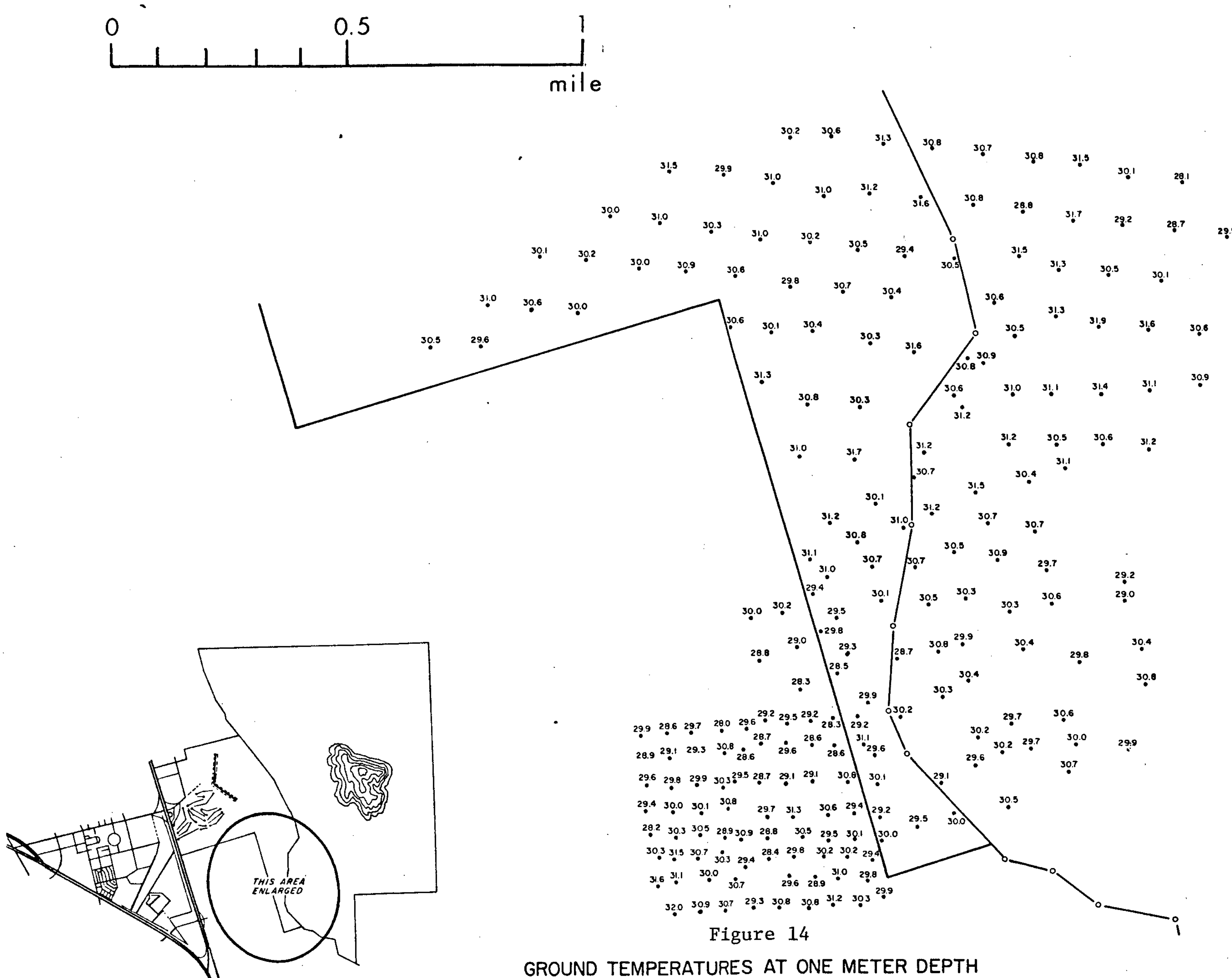


Figure 14

GROUND TEMPERATURES AT ONE METER DEPTH
(Degrees Centigrade)
(Raw Data of Shallow Thermal Survey)

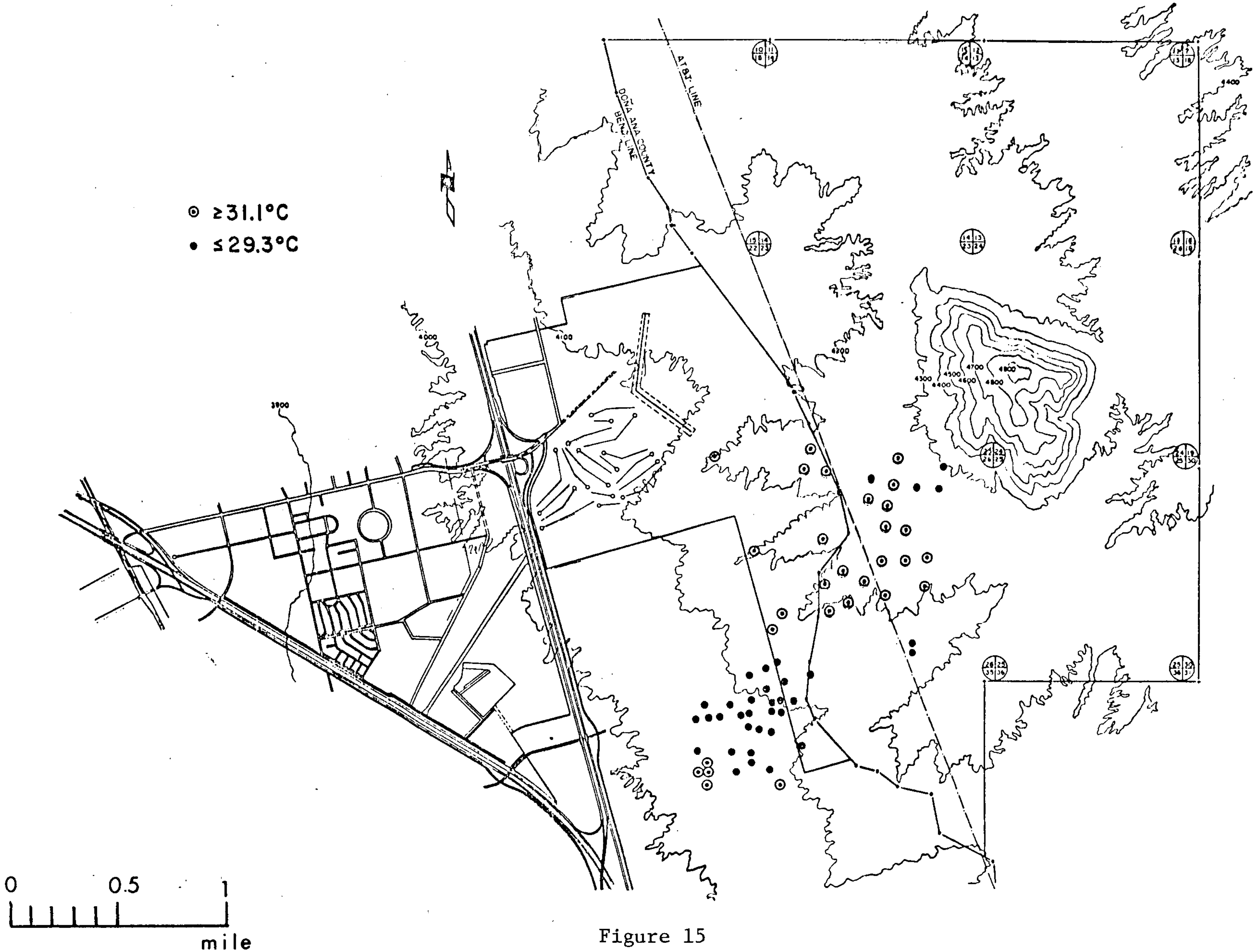


Figure 15

GROUND TEMPERATURES AT ONE METER DEPTH
(Degrees Centigrade)

(Analysed Shallow Thermal Data Showing Temperatures ≥31.1°C and ≤29.1°C).

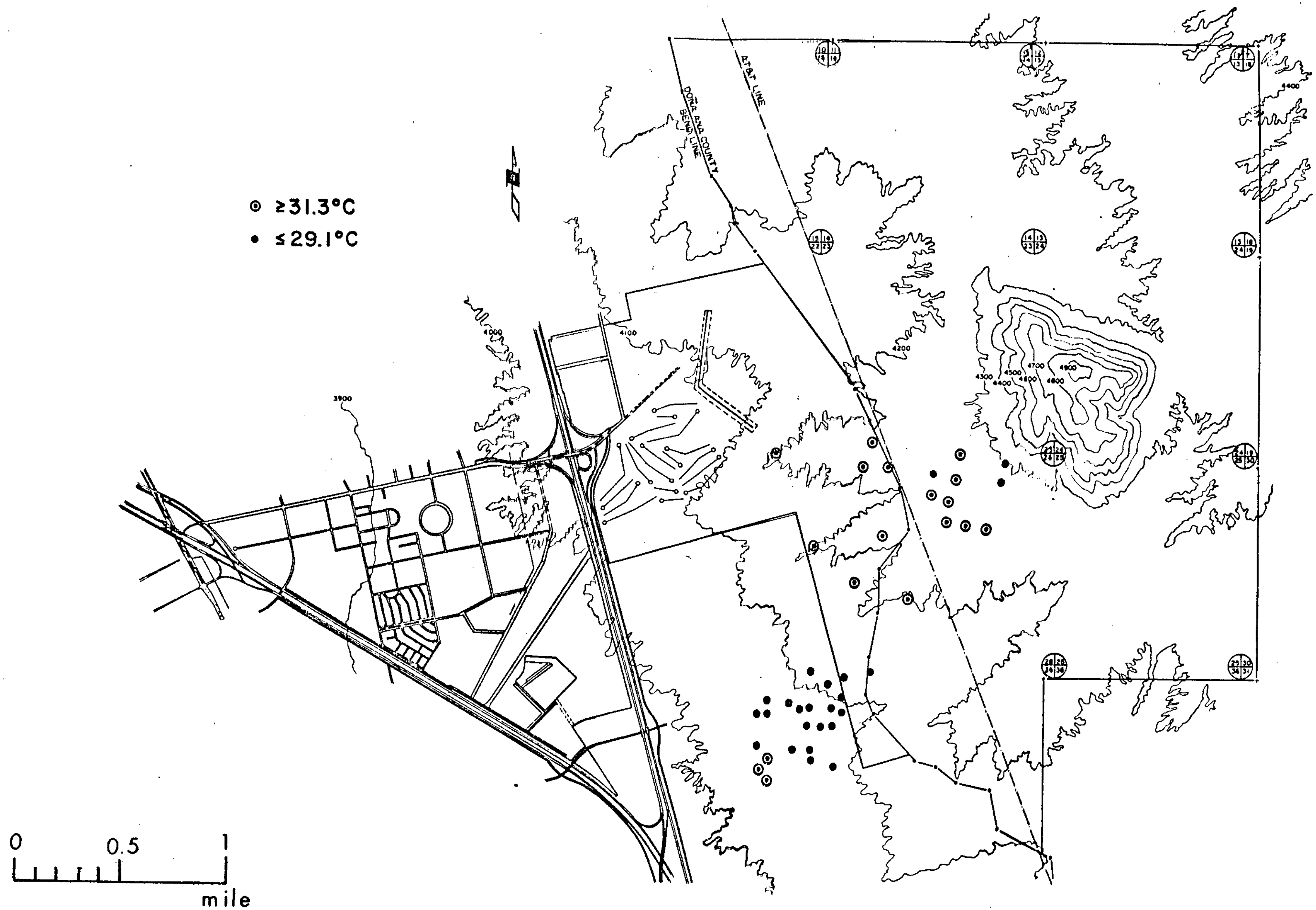


Figure 16

GROUND TEMPERATURES AT ONE METER DEPTH
(Degrees Centigrade)

(Shallow Thermal Survey Data Showing Temperatures ≧31.3°C and ≦29.1°C).

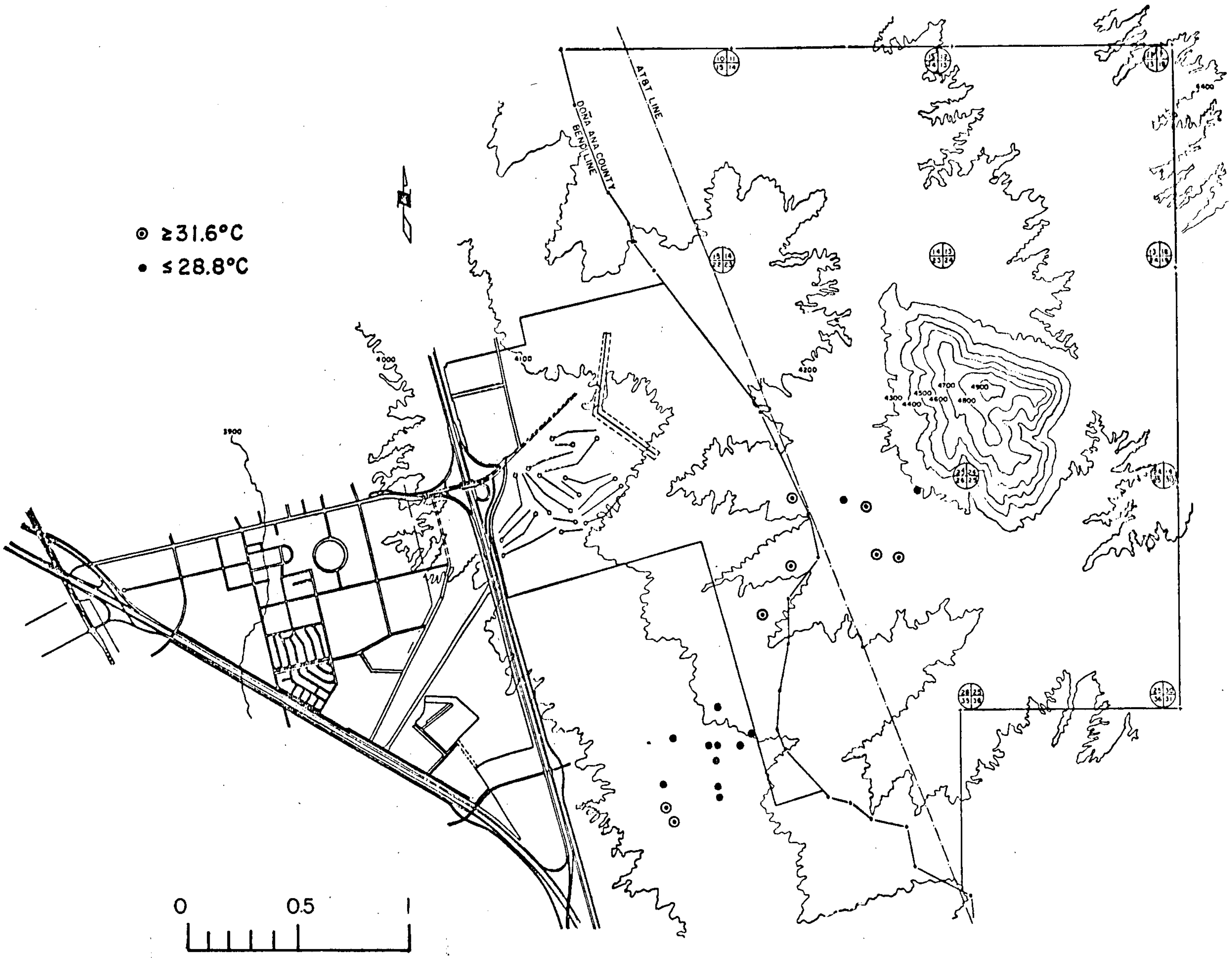


Figure 17

GROUND TEMPERATURES AT ONE METER DEPTH
(Degrees Centigrade)

(Shallow Thermal Survey Data Refined Further Showing Temperatures ≥31.6°C and ≤28.8°C).

CONCLUSIONS

On the basis of known facts, the following reasonable conclusions can be drawn. These are best estimates made on the basis of available data. The estimates can be refined further by more exploration work, but only actual drilling can confirm their validity.

1. The NMSU land east of Highway I-25 is an area of potentially useful geothermal energy resources.
2. The resource most likely occurs in the form of hot water at temperatures over 45°C.
3. The salinity of this hot water may be approximately 2000-2500 PPM.
4. On the basis of present knowledge, the best area for exploratory drilling lies on BLM land west of Tortugas Mountain. If the drilling is to be confined to the university land, it is proposed that two 1000 ft. deep wells be drilled at locations ① and ② shown on Figure 18.
5. Data on quantity can be obtained only through pumping tests on a test well drilled to the geothermal aquifer. No wells exist in the potentially hottest area at present for this estimate to be made.

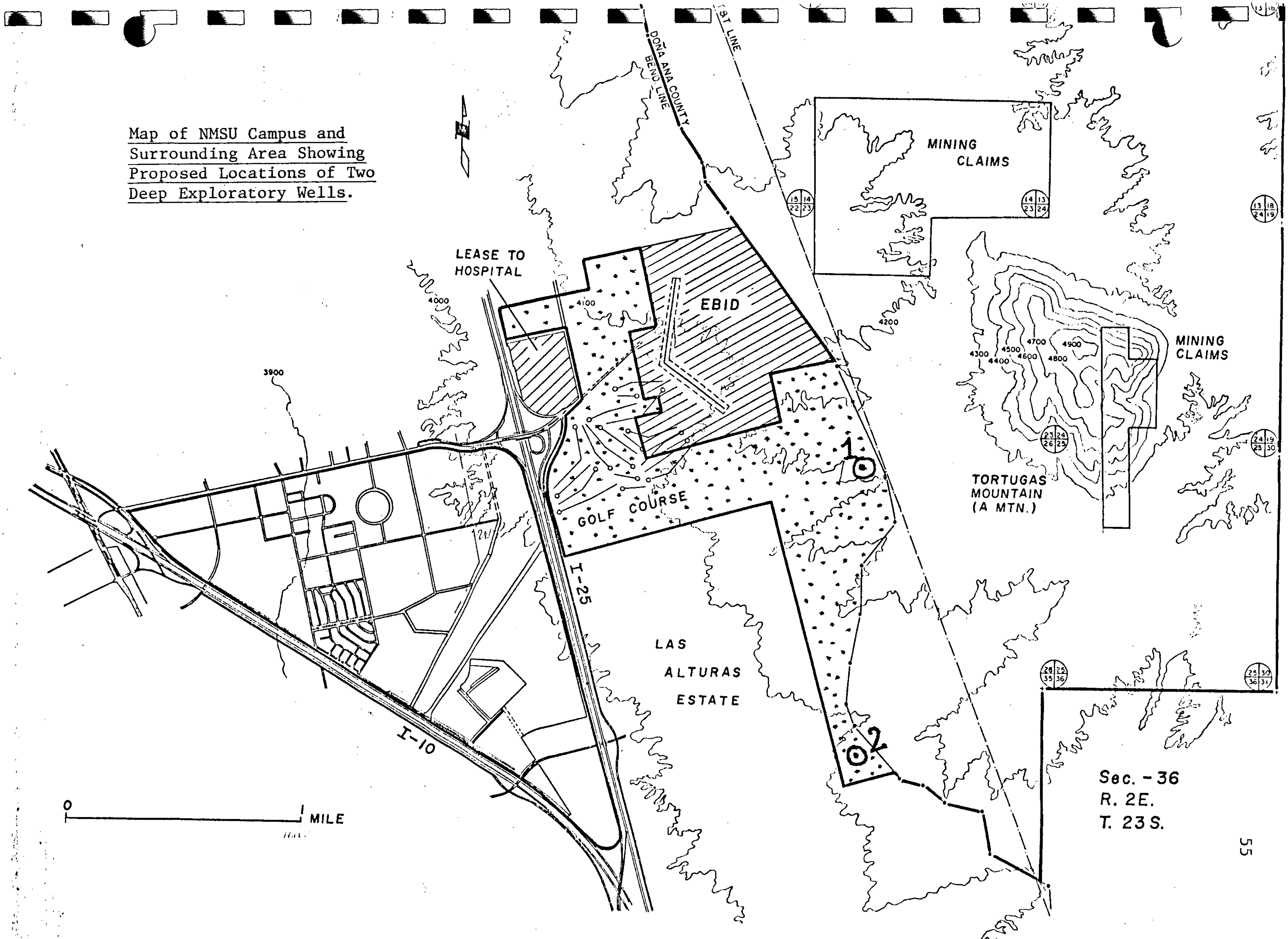

Map of NMSU Campus and Surrounding Area Showing Proposed Locations of Two Deep Exploratory Wells.
DOÑA ANA COUNTY
BEND LINE
LEASE TO HOSPITAL
EBID
MINING CLAIMS
MINING CLAIMS
GOLF COURSE
TORTUGAS MOUNTAIN (A MTN.)
LAS ALTURAS ESTATE
I-25
I-10
1
2
4000
4100
4200
3900
4300
4400
4500
4600
4700
4800
4900
0
1 MILE
Sec. - 36
R. 2E.
T. 23 S.

Figure 18

SECTION III

PRESENT CAMPUS HEATING AND COOLING SYSTEM

A good geothermal supply is useful only insofar as it matches the requirements of some system which can employ the geoheat, directly or indirectly. The present section describes the NMSU heating and cooling system. The sections of the report which immediately follow describe the conceptual designs and preliminary engineering equipment sizing for delivery systems to match the resource to the requirements. As is shown in these later sections, the potential for effective utilization ranges from very good to very poor, depending on the specific energy end-use under consideration.

NMSU relies upon the Central Heating Plant for provision of heating and cooling to all academic, research, general purpose and administrative buildings (except NMDA), all single-person dormitories and all athletic facilities. The gas-fired boilers generate steam at a plant efficiency such that 800 lbs. of steam are available for building use for every thousand cubic feet (Mcf) of natural gas (12.81 kg steam/m^3 gas). With a few minor exceptions, this steam is used to produce hot water in the heat exchangers at each individual building. There are separate heat exchangers for domestic hot water (supplied with fresh, cold water) and for space heaters (supplied with recirculated hot water). The hot water for space heating is pumped through finned-tube water-to-air heat exchangers; room temperature is controlled by thermostats which turn the blowers in these exchangers on and off or adjust dampers in some of the systems. Condensate from the primary exchangers is pumped into the return line to the central heating plant.

Steam to building space heaters is turned on during the month of October each year and turned off in April or early May. Essentially, the natural gas demand for the months May-September, inclusive, is for domestic hot water and swimming pool heating plus institutional cooking with steam. Given the University calendar for recent years, September is the only one of these months which is representative of domestic hot water demand under conditions of full-scale operation. For this reason, the four-year September average gas usage was used in this report as the domestic hot water demand for all months September-May, to which was added the actual (lower) figures for June, July and August.

Chill water for cooling is produced by two 1500-ton and one 1000-ton compression refrigeration units driven by 4350-volt, 3 phase electric motors. On a hot June/July day each driver will be drawing as much as 150 amperes. One of the three chillers operates all year around because a significant air-conditioning load is always required for the computer center and the studios of KRWG-TV as well as for certain minor cooled installations. There are no individual integrating electric meters on any machines/or buildings on campus; thus, it is very difficult to determine the proportion of the total electric consumption of the campus which is required for cooling. This is in contrast to the natural gas usage, which, as previously mentioned, can be reasonable apportioned between domestic hot water and space heating. Chill water from the central compression refrigeration units is piped to the individual buildings, where it is pumped through finned-tube air-to-water heat exchangers to cool the circulating building air and the makeup fresh air.

The majority of the buildings have direct tunnel connections to the utility tunnels which carry electricity, steam, chill water, and potable water over the large proportion of campus. Connection to some of the older and more remote buildings is via buried lines from the nearest tunnel location.

Semiannual consumption of natural gas and electricity for the principal buildings on campus is shown in Figure 19. It may be noted that gas consumption has risen somewhat over the past five years but that electricity consumption has remained essentially constant. Since there is reason to believe that gas consumption is related to number of users (especially as far as domestic hot water/athletic activities are concerned); the consumption data and cost data for gas (semiannual) are shown in Figure 20, on a per student basis. (Main campus total registration is the figure used in the divisor). With seasonal fluctuation allowed for, annual gas consumption per student has remained essentially constant at 28 Mcf/student over the past five years. However, gas expense per student has risen at a rapidly increasing rate to the point that it is nearly four times the fall 1972 figures ($5.26/student to $20.23/student,semiannually). Similar data for electric consumption and cost per student is shown in Figure 21.

Semiannual use of electricity per student has declined from 2803 to 2350 KWH/student, but expense has more than doubled in the past five years ($29.67/student to $68.86/student, semiannually).

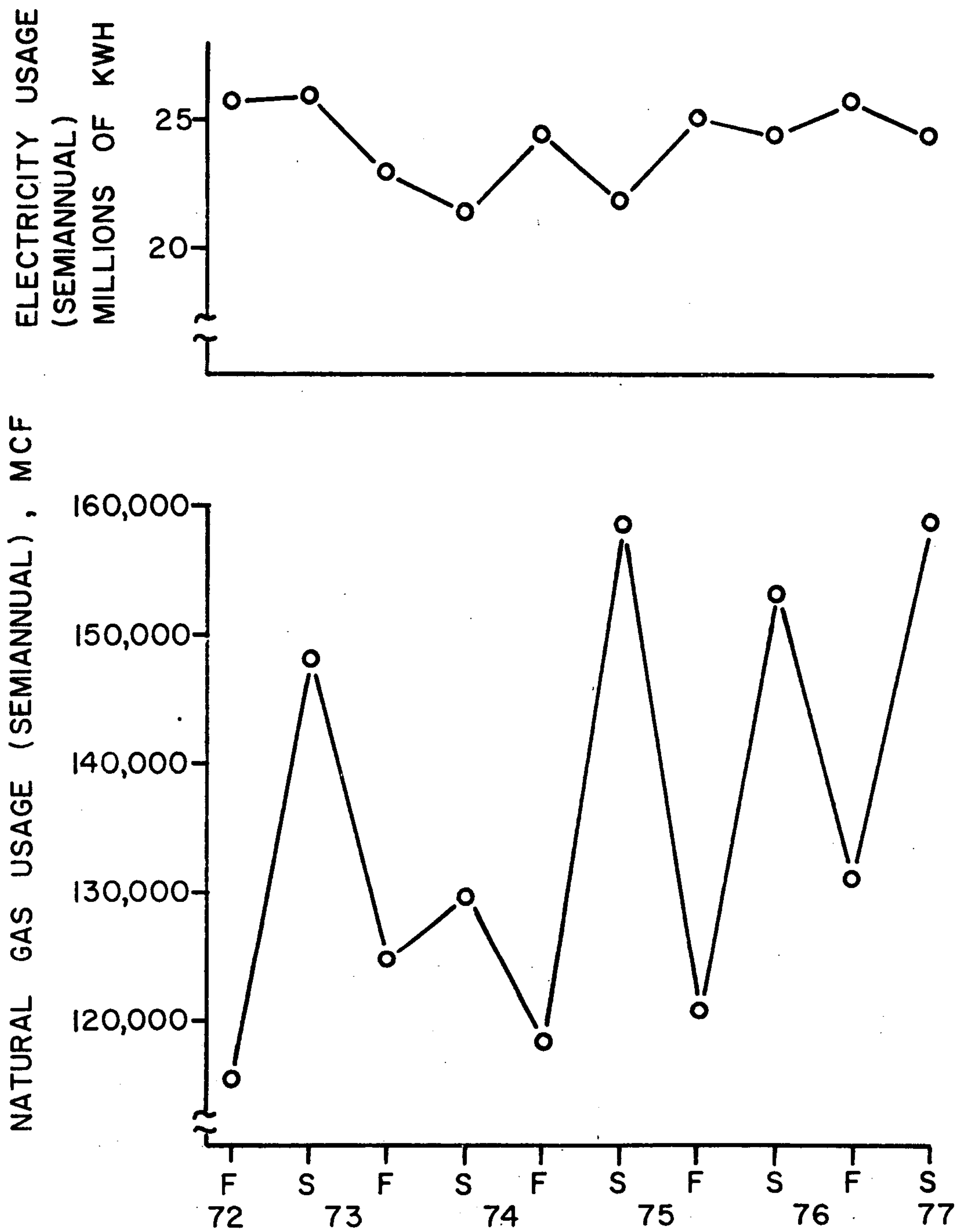


FIGURE 19
SEMIANNUAL GAS AND
ELECTRICITY USAGE 1972-1977

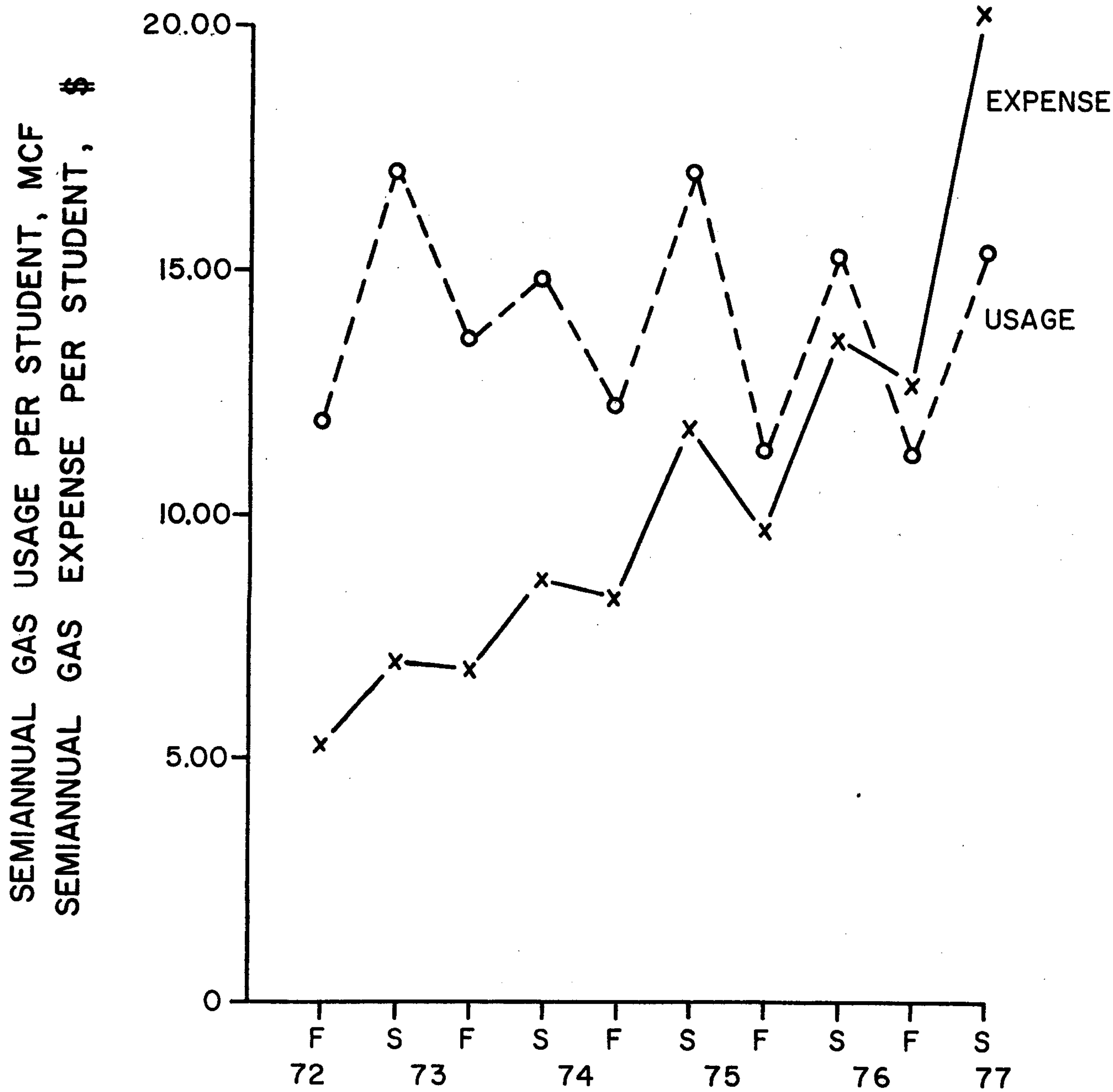


FIGURE 20
NEW MEXICO STATE UNIVERSITY
NATURAL GAS USAGE & EXPENSE,
1972 - 1977

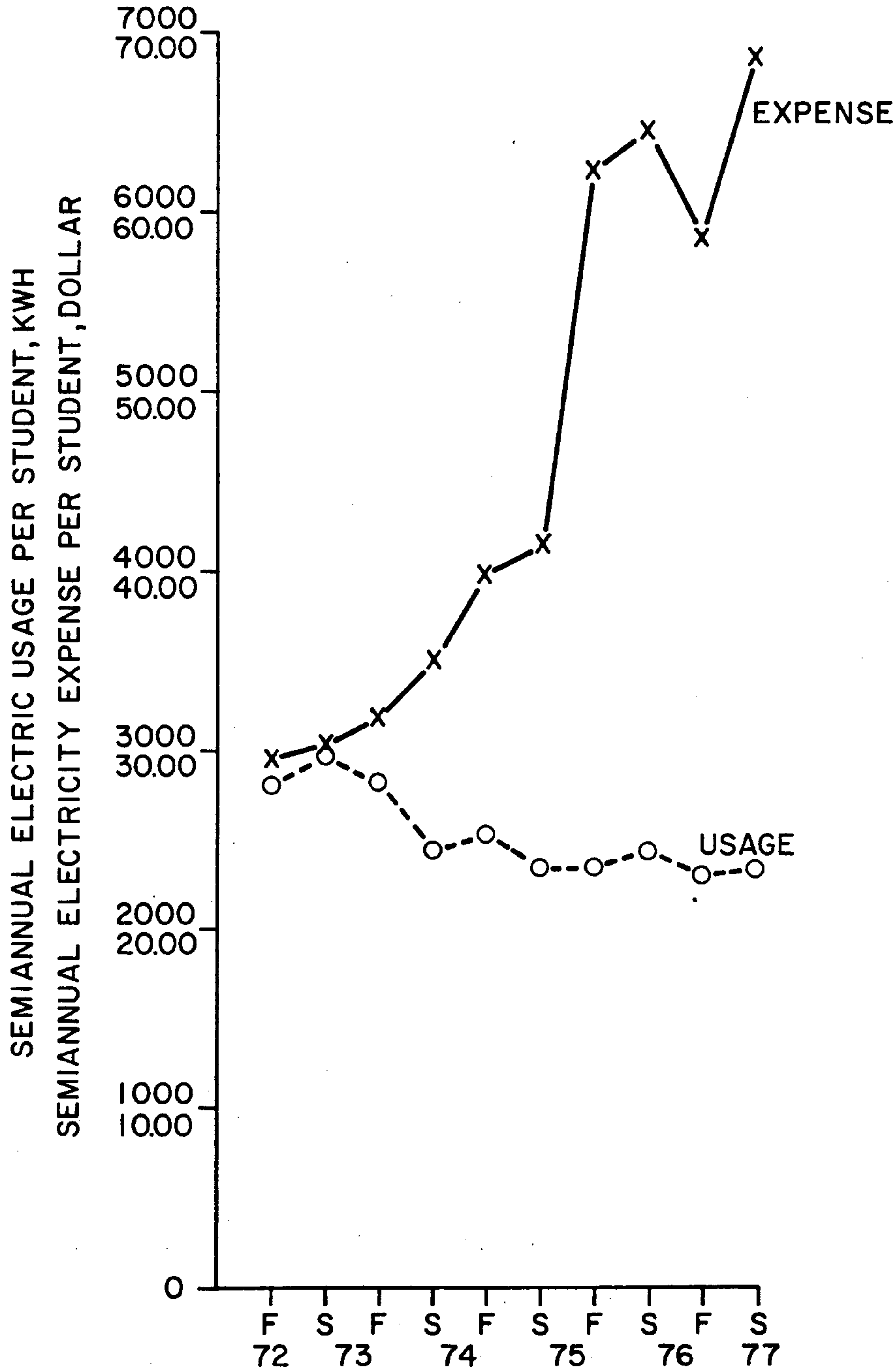


FIGURE 21
NEW MEXICO STATE UNIVERSITY
ELECTRICITY USAGE AND EXPENSE
(SEMIANNUAL, PER STUDENT) 1972-1977

The apportioning of electricity consumption between refrigeration (space cooling) and other uses can only to approximated. The range of figures estimated from the available data (ampere charts for the compressors, change in substation gross consumption from spring to summer) is from 7.6 million KWH to 13.7 million KWH annually, with annual cost in the $220,000 to $400,000 range.

The "true" energy cost of heating and cooling campus buildings also should include the electricity used to power the chill water and hot water pumps and part of the electricity required to operate the building fans. This element has been omitted from our calculations and estimates since it would not change appreciably if substituting a geothermal energy source were accomplished for one or more elements on the total load.

Calculation or estimation of various segments of the campus energy demand is included in the following sections of the report dealing with the possibility of geothermal energy substitution in various applications.

OVERVIEW ASSESSEMENT - BEST GEOTHERMAL APPLICATIONS ON NMSU CAMPUS

Since the geological evidence points to a liquid-dominated geothermal resource of reasonable temperature (possibly 80° - 120° C) at a reasonable depth (ca. 2000 feet (610 meters)), a variety of possibilities for energy use of this resource were screened for technical and economic feasibility. Each of the four following cases, plus combinations of the first three, were analysed in depth:

1. Domestic Hot Water Heating
2. Space Heating of Buildings
3. Cooling of Buildings
4. Electricity Generation

The following paragraphs summarize the technical and economic factors which determine the "best" and the "unlikely" cases of applications of geothermal energy. In the section of the report which follows, each case is analyzed in detail.

DOMESTIC HOT WATER HEATING

Domestic hot water is defined as potable water used for sanitary and other domestic purpose. It is principally used in the dormitories, athletic facilities, and the student center at NMSU. Domestic hot water, and other non-space heating uses, accounts for 48% of the natural gas consumption at NMSU. The best application of the geothermal resource, yielding the greatest return on investment for the least investment, would be to heat as much of the domestic hot water for the campus as possible (at least 60% of it) by exchange with the geothermal resource. The investment is minimized by three factors: 1) The campus fresh water supply tank is only a few hundred meters from the proposed well site; 2) Only a relatively small one-way pipeline is required; and 3) A greater amount of heat is extracted from the geothermal fluid per unit of pumping energy than for any other application. If the test well shows that only limited (ca. 200-300 gpm) pumping is feasible, this would become the only technically and economically feasible option.

SPACE HEATING

Since all campus buildings are presently heated with hot water, space heating is technologically possible within the range of expected temperatures. It would be necessary to exchange the heat from the geothermal fluid to a non-corrosive buffer solution in a rather long and large circulating loop (pipeline), running from the wellfield to the main part of campus and back again. For various reasons, this option should be combined with provision of domestic hot water. If the production rate from multiple wells can average 600 gpm and can sustain up to 4000 gpm for 12 hours or so, the very large plant investment required to replace 90% of the campus natural gas demand should pay for itself in six to eight years. Assuming a bond issue could be floated for plant/pipeline/well construction, this option would become the most desirable one, if the geothermal resource proves out at a high pumping rate.

COOLING

If the exchangers and pipeline for space heating are constructed, addition of cooling would not involve extraordinary capital expense. However, the state-of-the-art is such that cooling is not technically possible unless the geothermal fluid is at about its maximum possible temperature of 248°F. (120°C). Even though the resource may be sufficiently hot, the application is too wasteful of pumping energy and cooling water to be considered, unless a very shallow (200-300 meters) well is sufficient. Even then, the matter is dubious. However, if the full scale heating option is adopted, cooling could be added at such later dates as more thermally efficient absorption refrigeration systems are developed.

ELECTRICITY GENERATION

While electricity generation is often considered in connection with geothermal resources, such power generation is feasible only with high vapor content system. Although it is presently technically possible to use the energy on hot water to produce electricity, the state-of-art is at least five years away from practical application, perhaps more.

There is some thought that a liquid-vapor, 200°C resource may exist on the NMSU campus at a depth of 1.0 to 3.5 kilometers. Until better geological information is obtained, the very high expense of test drilling for this resource may be difficult to justify. For these reasons, electricity generation does not seem to be a near-term application of geothermal energy on the NMSU campus.

SECTION IV

CONCEPTUAL DESIGN AND PRELIMINARY COST ESTIMATES - ALTERNATIVE SYSTEMS

This section of the report presents results of conceptual engineering designs and of preliminary cost estimates for various alternative systems and configurations. The reason for presenting most alternative figures on only part of the campus is that the buildings using the most domestic hot water and also the larger consumers of heating steam and chill water are on the eastern part of the main campus closest to the geothermal field. Another reason is that geothermal fluid production may be insufficient for the entire campus. However, cost estimates for total feasible replacement have also been made.

The present report treats the cost and savings data essentially in two ways. One assumes constant prices of natural gas and of electricity (at $2.10/Mcf and $0.03/KWH, respectively) for the next five years and uses 1977 capital costs of construction. The other applies escalation factors over a fifteen-year project life. It is believed that the first approach is quite conservative in predicting the economic benefit to be obtained but that the second has merit in being more realistic, as well as more optimistic, about the monetary benefit of substituting geothermal energy for fossil fuel for campus uses. Cost escalation analysis is presented in a subsequent section of this report.

HOT WATER AND SPACE HEATING

In order to evaluate various configurations, estimates of demand for domestic hot water and for space heating were made for various building on the eastern part of the campus. These were compared with total campus demand. Demand for domestic hot water for indivdual building was pro-rated, according to design capacity of the individual building, to total University demand. This average figure is 30% of design capacity. This is a good method of estimation, although it could be in error for any given building. In the absence of any usage data for individual buildings, it is the best estimate possible.

Demand for space heating is more closely related to design capacity for each individual building. Most of the newer buildings on campus are designed to maintain comfortable interior temperatures at 0°F (-17.8°C) outside temperature, some are at 10°F; since the basis for a heating degree-day is 65°F, then, at capacity, the 24-hour steam consumption of most of the newer buildings would 65 degree-days. (Note: There is no Celsius equivalent of Fahrenheit degree-days.) Climatological data given 30-year average heating degree-days for University Park, by the month, are available (See Table 3). Total heating degree-days (3167) multiplied by a design factor calculated on steam capacity for 65 degree days yields steam demand for space heating for each individual building. This is then connected to Mcf gas required at the Central Heating Plant. Application of the above methods of estimating gas usage for domestic hot water and for space heating, respectively, to the entire campus capacity (estimated 20% usage of Pan American Center) yielded as total estimate of 285,600 Mcf (8,087,355 m^3) of natural gas to be supplied per year. This compares with 284,200 Mcf actual usage in 1976. This is 1/2 of 1% error, overall. It is believed that the error for individual buildings is not high, but no actual individual data are available.

The data for individual building requirements for heat from geothermal fluid are calculated in a similar manner. For domestic hot water a factor

TABLE 3

CLIMATOLOGICAL DATA FOR UNIVERSITY PARK
(30 Year Average Data, 1941-1970)

Month	Average Daily Temperature, °F	Heating Degree-Days
Jan	41.7	722
Feb	46.0	532
Mar	51.3	425
Apr	60.0	171
---	----	---
Oct	61.2	133
Nov	48.9	483
Dec	42.4	701
	TOTAL HEATING DEGREE-DAYS	3167

of 10 pounds building hot water per pound of steam demand was used, for space heating a factor of 50 pounds of water per pound of steam.

Tables 4 and 5 show calculated requirements of natural gas for domestic hot water heating and for space heating, respectively, for selected buildings on the east side of campus. An attempt was made to select a group of buildings which totaled about 50% of the campus requirements for the type of heating involved. The stipulation was exceeded in the first case and not quite reached in the second.

Calculation was then made of the size of equipment and the temperature and volume of a geothermal resource which could supply the projected demand. (Seven buildings or complexes used 60% of the domestic hot water; 16 buildings or complexes using slightly less than 50% of the hot water for space heating.)

DOMESTIC HOT WATER

The economic optimum pipe diameter for pumping 170 gpm (1.08×10^{-2} m^3/s) of water is 4 or 5 inches (10.1 - 12.7 cm). However, the 170 gpm is a 24-hour average figure, so a six-high pipeline (15.2cm) and seven-inch well (17.8 cm) were provided to allow for peak loads and future expansion. Since some buildings require hotter water than others, a delivery temperature of 158° F (170° C) is allowed for. An average flow of geothermal fluid of 200 gpm (1.26×10^{-2} m^3/s), with 500 gpm ($3.15 \times 10^{-2} m^3/s$) maximum, at 176° -248° F (80° -120 C) is incorporated in the calculation. The higher the temperature, the smaller the well-flow and the smaller the heat exchanger. If temperature is as low as 165° F (74° C), delivery conditions can still be met by increasing heat-exchanger size.

Geothermal fluid of the temperature and quantity required to supply the seven buildings in Table 4 with domestic hot water would mean that

TABLE 4

DOMESTIC HOT WATER CAPACITY & ESTIMATED DEMAND
-SELECTED BUILDINGS ON EAST SIDE OF CAMPUS

Building	Hot Water Heater Capacity, lbs. Steam/hr.	Average Yearly Gas Usage Mcf	Average Hot Water Flow, gal/min
Pan American Center	3,300	10,068	19.80
Alumni Avenue Dormitories	6,229	19,005	37.37
Physical Education Complex	2,640	8,005	15.84
Natatorium	549	1,675	3.29
Women's Residence Center	5,466	16,677	32.80
Garcia Hall Dormitories	9,014	27,502	54.08
Corbett Student Center	1,250	3,814	7.05
TOTALS	28,448 (12,904 kg/hr)	86,796 ($2.46 \times 10^6 m^3$)	170.68 ($1.08 \times 10^{-2} m^3/s$
CAMPUS TOTALS	42,090 (19,092 kg/hr)	136,963 ($3.88 \times 10^6 m^3$)	252.54 ($1.59 \times 10^{-2} m^3/s$

TABLE 5

SPACE HEATING CAPACITY AND ESTIMATED NATURAL GAS USAGE

-SELECTED BUILDINGS[1]

Buildings	Space Heating Steam Capacity, lbs./hr.	Estimated Average Annual Gas Usage Mcf	Annual Cost of Gas at $2.10/Mcf
O'Donnell	3,760	5,496	$ 11,542
Branson Library	6,828	9,880	20,959
Hardman	900	1,316	2,763
Jacobs (Music)	823	1,203	2,526
Little Theatre	8,37	1,223	2,569
Guthrie	1,495	2,185	4,589
Williams (Art)	1,254	1,833	3,849
Milton	3,733	5,457	11,459
Garcia Annex	1,209	1,767	3,711
Corbett Center	6,500	9,501	19,952
Women Res. Center	3,036	4,438	9,319
Regents Row Droms	2,087	3,051	6,406
Natatorium	1,374	2,008	4,218
Phys Ed Complex	3,300	4,824	10,130
Alumni Ave. Dorms[2]	3,460	5,977	12,552
Garcia Dorms	5,007	7,319	15,369
Pan Am Center	13,600	3,976[3]	8,349[3]
TOTALS	59,203	71,554[3]	$150,262[3]
CAMPUS TOTALS	112,565	148,632[3]	312,127[3]

NOTES [1]) Arranged in approximate decreasing order of distance from geothermal well-field
[2]) Rated capacity at 55 degree-days/day
[3]) Based on 20% utilization of PAC heating system

a capital expense of \$548,000 to \$590,000 would be required to make this energy available. This expense includes a 6 5/8" producing well, a well-head heat exchanger, 11,000 ft. of 6" insulated pipeline, a reinjection well and security building. Operating expenses are estimated at \$13,400 to \$38,200 per year. With 6% interest rate, the savings in natural gas (at \$2.10 Mcf) (level cost assumption) would repay the capital cost in 4.4 to 4.8 years. The savings from this application alone represents 30% of the total NMSU gas consumption (see Table 6). A block diagram illustrating the relationship of components is given in Figure 22. An economic evaluation based on predicted fuel price escalation is given in a subsequent section.

SPACE HEATING

While it is possible to estimate a reasonably consistent month-to-month average demand for domestic hot water, this it obviously not possible for space heating. In its place, an average temperature of 42° F (5.6° C) and the peak load was calculated for an outside temperature of 10° F (-12.4° C) (nighttime minimums seldom drop below 10° F in Las Cruces). Sizing of equipment was calculated from the peak demand figures; pumping energy requirements were based on a heating season of 137 "normal winter days." For all practical purposes this is equivalent to the 3167 average heating degree-days in Las Cruces.

The need to size for peak demand results in extremely high equipment cost. Since much of the capacity is unused, except for perhaps 20 hours a year, the amortized capital costs plus operating cost far outrun the economic benefit from savings of natural gas based on level 5 year prices. The most optimistic design assumptions would indicate a 20 year amortization period at 6% interest.

Table 6

COST/BENEFIT ANALYSIS FOR DOMESTIC HOT WATER (7 BUILDINGS)

Geothermal Fluid Temp. °F(°C)	Capital Cost, $	Operating Cost, $/yr.	Yearly Benefit (Operating Margin)	Amortization Period At 6% Interest
176°(80)°	590,000	38,200	144,000	4.8 years
212°(110°)	560,000	34,000	148,200	4.6 years
248°(120°)	548,000	31,400	151,800	4.4 years

NOTE: Based on level price of $2.10/Mcf for natural gas

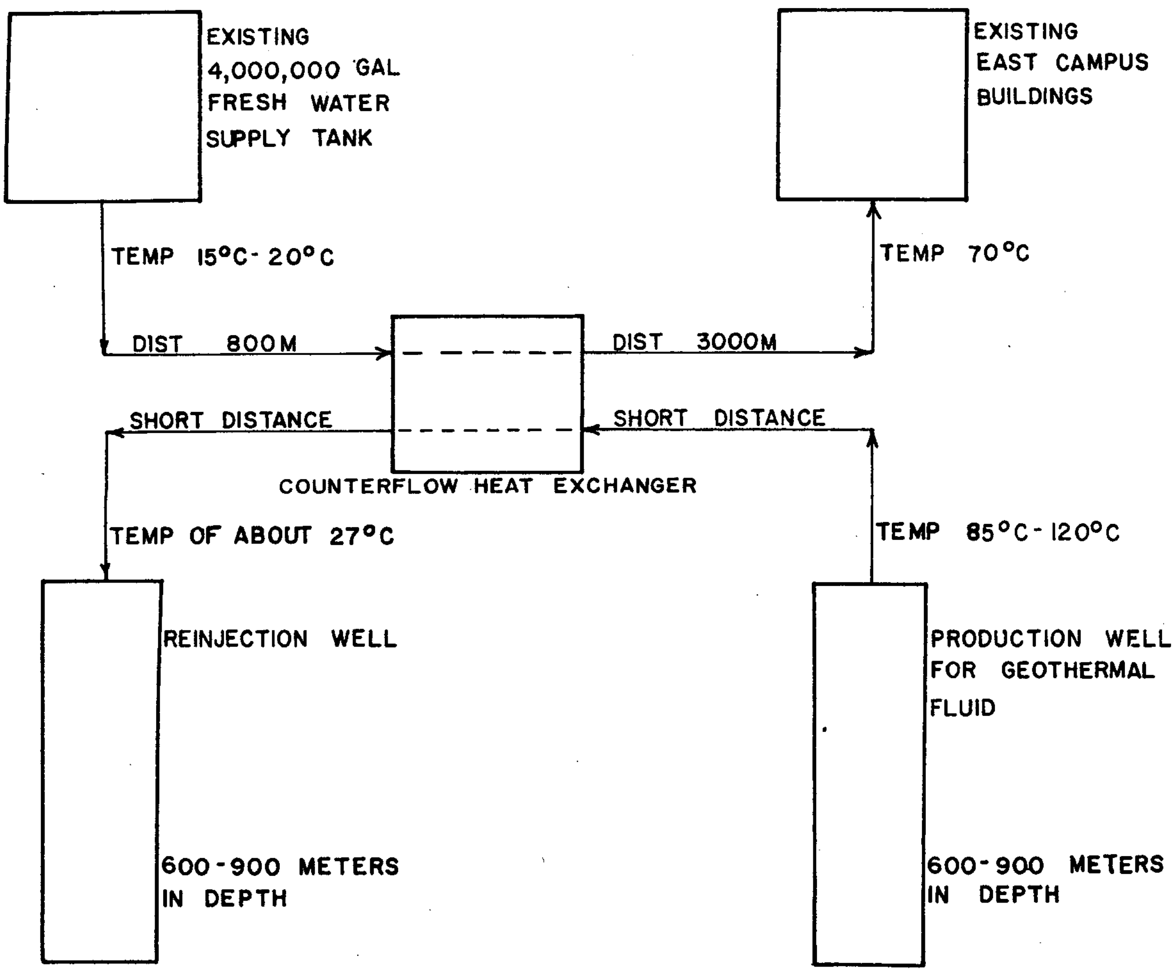


FIGURE 22
DOMESTIC HOT WATER SUPPLY SYSTEM
(GEOTHERMAL ENERGY UTILIZATION)

This situation is not as economically hopeless as suggested by the cost figures in Table 7 for two reasons: First, escalation in price of the natural gas to be replaced; second, the high capital cost is mostly incurred because of the indicated need to circulate up to 4140 gallons per minute (0.261 m^3/s) in the heating water pipeline, a loop 19,000 feet (5,791 m) in estimated length. A minimum of a 12" (30.5 cm) line and possibly a 14" (35.6 cm) line is called for to meet this design criterion. Also, a nine-inch (22.9 cm) well size is called for, with a maximum geothermal fluid pumping rate of 2000 gpm (0.126 m^3/sec).

The large pipeline, well and heat exchanger size results from the configuration of the building heaters, which are constructed for about a 12 to 15° F (6.7-8.3° C) drop in temperature of the hot water across the heater. In this study it was assumed that this drop could be pushed to 20° F (11.1°C), but any greater use of the heat-carrying capacity of the circulating fluid would require modification of the heating equipment in the individual buildings. This option is not contemplated in the present study; it is one which should be seriously considered in future, more exhaustive analyses of the economic trade-offs involved in switching to geothermal heating. That is, the investment in the heat exchanger and circulating line and pumps could be considerably reduced by expending money on enlargement of the space heaters in the individual buildings, probably with an overall lower total capital cost and also lower operating cost.

APPLICATION OF COOLING CAMPUS BUILDINGS

General Considerations

The application of geothermal energy to building cooling involves only state-of-the-art technology; but, the technology is subject to certain

Table 7

COST ANALYSIS FOR SPACE HEATING AT

DIFFERNET TEMPERATURES OF GEOTHERMAL FLUID

Geothermal Fluid Temp °F (°C)	Pipeline Size (in.)	Heat Exchanger Option (1)	Capital Cost, $	Operating Costs $/yr.
176°(80°)	12	A	1,236,000	47,500
176°(80°)	12	B	1,274,000	41,300
176°(80°)	14	A	1,328,000	44,500
176°(80°)	14	B	1,365,000	38,400
212°(100°)	12	A	1,211,000	32,800
212°(100°)	12	B	1,231,000	30,900
212°(100°)	14	A	1,303,000	29,800
212°(100°)	14	B	1,323,000	27,900
244°(120°)	12	A	1,201,000	27,400
248°(120°)	12	B	1,214,000	26,500
248°(120°)	14	A	1,293,000	24,400
248°(120°)	14	B	1,307,000	23,500

NOTE: 1. Option A "minimum" heat exchanger area
Option B "maximum" heat exchanger area

2. Savings in natural gas, $150,252/year

limitations which make the option of questionable attractiveness.

Basically, any multi-building refrigeration air-cooling system, such as is used on the NMSU campus, requires a central plant for production of cold water ("chill water") at 39 to 42° F (4.0° to 5.5°C) which is circulated to the individual building chillers as explained in a earlier section. A "ton of refrigeration" is defined as 12,000 BTU/Hr of heat extracted from the air of the building. Refrigerating systems are rated by "coefficients of performance" (COP) which relate units of heat energy removed from the air per unit of energy expended in the refrigeration system. The NMSU system has a COP in the vicinity of 4, which means that 4 watt-hrs (thermal) are removed from the air for each watt-hr (electrical) used in the electrically-driven compression refrigeration units. Now, electrical energy is expensive because it is largely produced from fossil fuel with an overall efficiency of production and distribution of the thermal energy in the original fuel of perhaps 30%. This means that strictly in terms of watt-hr (thermal), the COP of the campus refrigeration system is only 1.2, or slightly less. This implies that ultimately almost one BTU of fossil fuel must be expended somewhere in order to remove one BTU of heat from campus buildings.

The serious drawback to present technology of producting refrigeration from low temperature thermal sources, such as hot geothermal fluid or solar-heated liquid, is that the absorption refrigeration units have an extraordinarily poor COP as compared with compression refrigeration units. The best units currently available would have a COP of only 0.67 for 120° C geothermal fluid. This means that we must expend one and one-half thermal units of heat energy for each thermal unit of cooling. This would not be a serious drawback if the thermal units were a "free good" at the location of the absorption chillers, but they are not.

Electricity energy (or petroleum energy) must be expended at the well-site to bring the hot geothermal fluid from its underground location to the refrigeration unit at the surface. Because of the design limitations of the presently available absorption refrigeration units, they not only have a low COP but can use only a small proportion of the heat energy (enthalpy) of the geothermal fluid. If the enthalpy of 120° C fluid (248° F) is assumed to be the same as pure water at 217 BTU/lb., then the 36 BTU/lb. which are usable by the absorption unit represents only 17% of utilization of heat energy above the standard datum of 0° C (32° F). This is in contrast with the domestic hot water heating application which would use 168 BTU/lb. for a 77% utilization of the heat energy in the (102° C) geothermal fluid.

For the purpose of this project, electrical pumping at 100% efficiency was assumed. On that basis, the substitution of electrical energy at one location for that now being expended at another could be directly compared. Comparisons of fossil fuel equivalents were also made. As may be seen later in the section, the two limitations described in the preceding paragraph combine to make it imperative to obtain hot water from a fairly shallow depth or else refrigeration cooling does not appear feasible.

DEMAND SIDE

The demand for chill water for summer cooling is very difficult to assess since there are no integrating meters on the refrigeration compressors ("chillers") at the central heating plant. Part of the problem is that the computer center, the television studio and a few other installations on campus require chill water all year around. Two approaches were taken to estimating the average demand from capacity data (this is about 65% of total campus demand) of the 16 buildings in Table 5-3.

One was a review of the selected amperage charts for the chiller drivers on "typical summer days"; the other was analysis of winter-summer total power usage at the main sub-station. These figures agreed within 5%, so the lower one (1250 tons average, 2000 tons peak) was employed for preliminary design purposes. This corresponds to 1014 kilowatts average demand for electrical energy at the present units. It is recognized that these figures are much less reliable than the heating demand figures because of unknown differences in building usages, effect of insulation and insolation, etc., during the nominal 150-day cooling season. No steps toward a firm engineering design of a new cooling system could be or should be taken until definitive measurements of the cooling load of individual buildings, as they now exist and as they may be modified by conservation methods, are performed.

SUPPLY SIDE - DESIGN AND ECONOMICS

As seen in Figure 23 provision for cooling would require addition of absorption refrigeration units and an associated cooling tower to the equipment required for space heatings. To allow for peak demand and line losses, three 1000-ton York chillers are specified, along with a 3100 sq. ft. cooling tower, rejecting 62,000,000 BTU/hr. Using the standard assumption of well depth of 2000 feet, the total electrical requirement for the system would average 612 kilowatts, of which 487 is for well-pumping and the remainder for circulation line, cooling tower, etc. In thermal terms, only 36 BTU/lb of heat energy are being removed from the fluid, in comparison with the 10 BTU/lb fossil fuel equivalent required to pump it from the ground.

Assuming a geothermal space-heating plant is already in place, expansion of the plant for cooling the same 16 buildings would cost

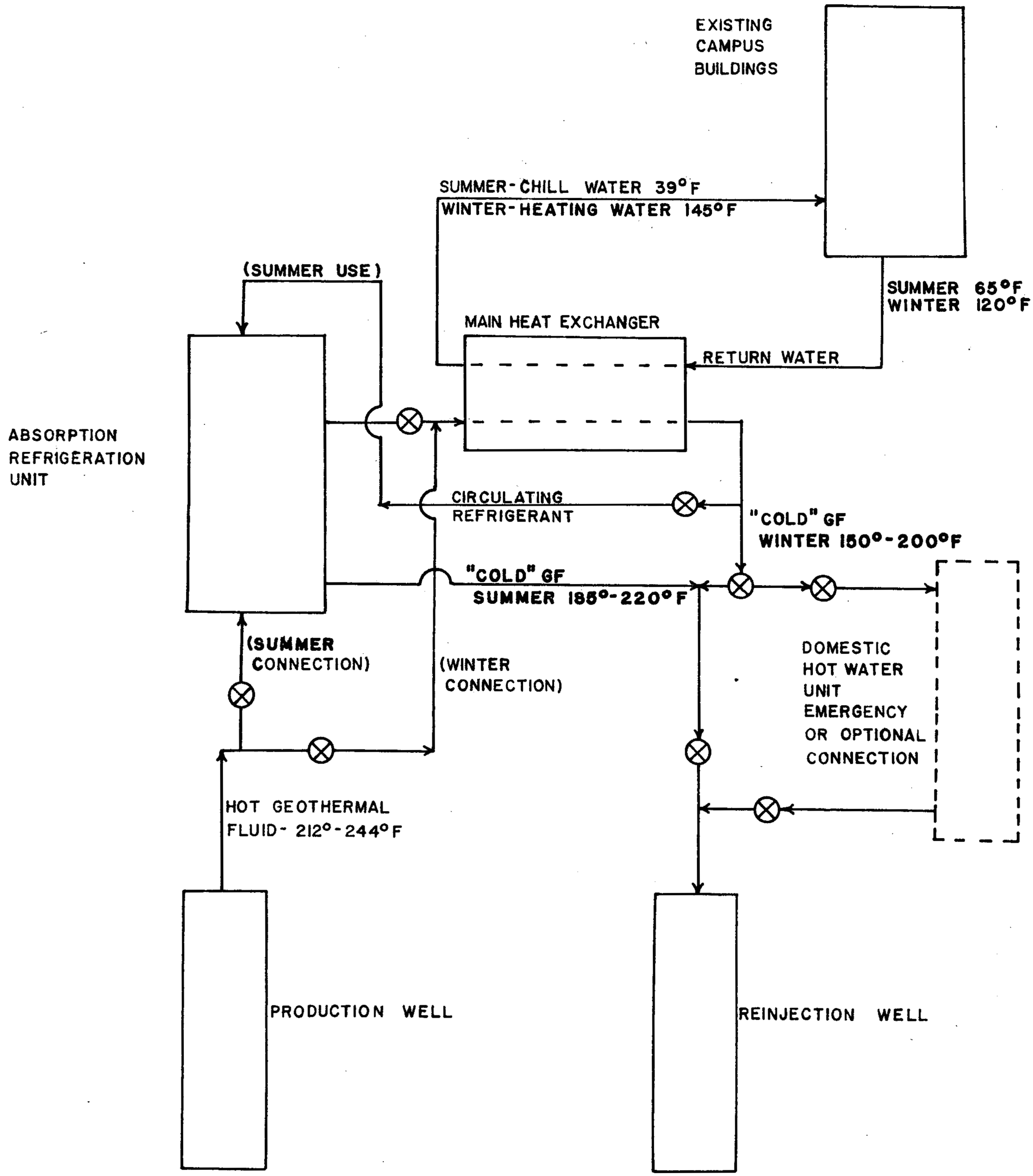


FIGURE 23
COMBINED SPACE HEATING AND COOLING
(GEOTHERMAL ENERGY UTILIZATION)

slightly less than $600,000. This is the marginal (incremental) capital cost. The marginal (incremental) savings is estimated at $33,000 per year (150-day cooling season). The marginal savings will obviously not pay for the marginal investment.

<u>If</u> the required 120° C geothermal fluid is available at only about 1000 ft. (about 300 meters) depth, the annual savings increases to $59,300 per year. At 6% interest, in this latter case the capital investment would be recoverable in 15.5 years - which makes it a marginal and risky investment. Note that escalation in fuel cost is not a factor in this calculation since we are talking about electrical energy exclusively both for the present system and the geothermal system.

The tentative conclusion is that building cooling is not a viable use of the geothermal resource within the constraints of present assumptions. Changes in technology, a higher temperature of the resource and a shallower depth of well might combine to make the application attractive from fiscal and energy effectiveness standpoints.

ELECTRICITY GENERATION

NMSU at the present time relies upon El Paso Electric Company for all its electrical needs. The campus has an average demand of approximately 5000 kilowatts with a peak load of approximately 8500 kilowatts. The electricity is used primarily for lighting, air conditioning chillers and HVAC equipment.

Figure 24 is a schematic representation of a Binary Electrical Generating System. A Binary System was considered rather than a Steam Flashing System because of the relatively low temperatures expected in the Las Alturas area. In the Binary System, the geothermal fluid is pumped from the producing well and passed through a heat exchanger where

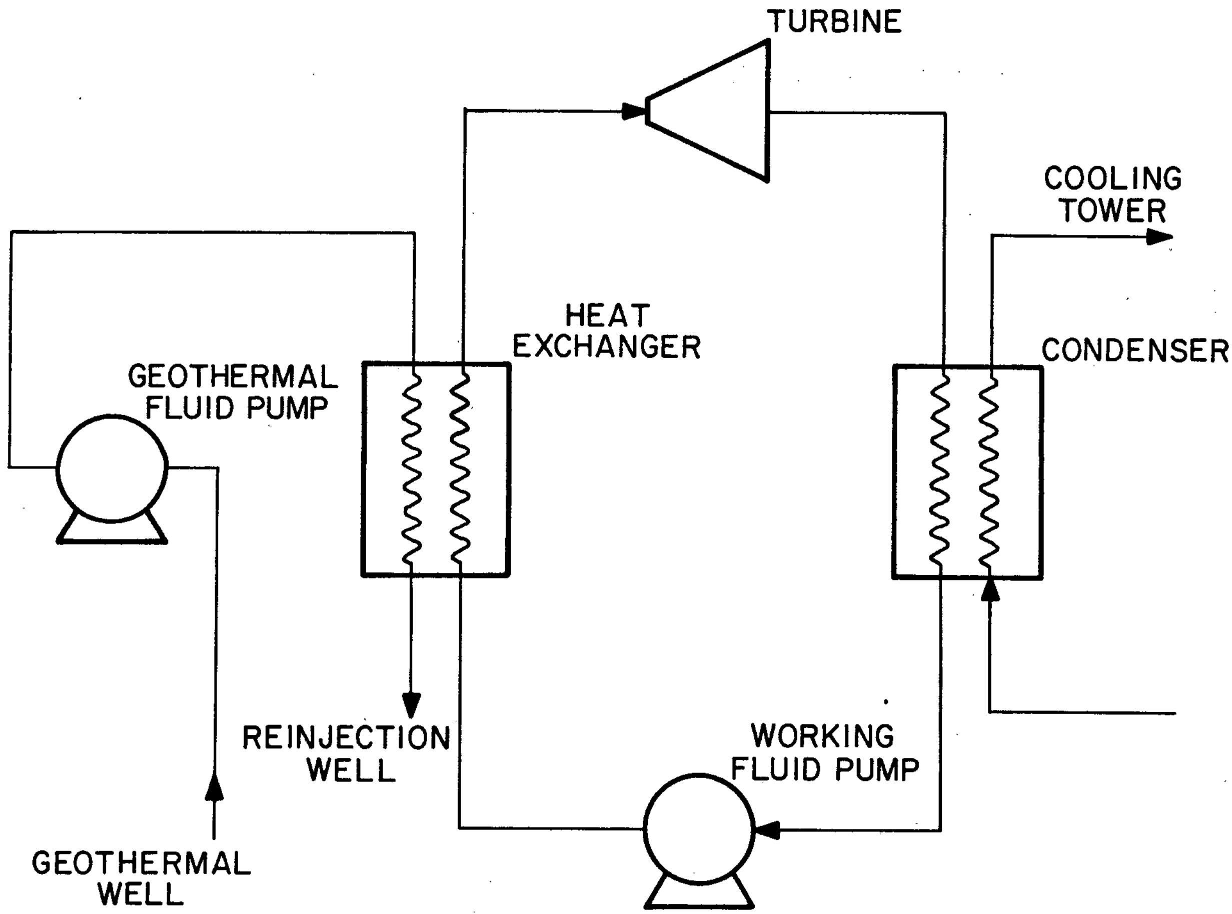


FIGURE 24
BINARY SYSTEM FOR GEOTHERMAL ELECTRICAL GENERATION

it heats the working fluid. The geothermal fluid is then reinjected. The working fluid, after passing through the heat exchanger, is expanded through the turbine producing work to generate electricity. The working fluid is then condensed, the heat being rejected to the atmosphere in the cooling tower. The system in the schematic also shows parasitic losses due to pumping the geothermal fluid and losses due to pumping the working fluid to the pressure required at the turbine inlet.

A Fortran IV program from reference [26] was used to thermodynamically analyze the system shown in Figure 24. The results of the analysis of geothermal fluid temperatures of 100° C and 120° C for seven different working fluids are shown in Table 8. The table is a tabulation of net output, geothermal pumping energy, working fluid pumping energy and the heat rejected. The net output, geothermal pumping energy and working fluid pumping energy add up to 100%, the total output of the generator. Thus, for R22 using 100° C geothermal fluid, 31.9% of the power generated is available, 60.2% of the generated power is used to pump the required geothermal fluid, and 7.8% of the power is used to pump the working fluid. The cooling tower has to reject 11.99 times the energy generated by the turbine.

The values shown in Table 8 are very optimistic since only working fluid pump energy and geothermal fluid pumping energy with a 100% efficient pump are considered. The geothermal well is assumed to be 2000 ft. deep and the pumping power is the energy to bring the fluid to the surface. Additional parasitic losses that are not considered are additional pumping energy to reinject the geothermal fluid, cooling water pumping energy and cooling tower fan energy.

Table 8

GEOTHERMAL ELECTRICAL GENERATION

Working Fluid	Geo. Temp.	Net Output%	Geo. Fluid Pumping % Output	Working Fluid Pump % Output	Heat Reject % Output
R22	100° C	31.9%	60.2%	7.8%	1199%
	120° C	59.3%	31.1%	9.8%	791%
R32	100° C	30.7%	59.1%	10.2%	1173%
	120° C	54.3%	24.8%	20.9%	648%
R114	100° C	16.5%	81.3%	2.3%	1638%
	120° C	54.7%	42.6°	2.7%	1113%
R115	100° C	23.6%	64.9%	11.5%	1296%
	120° C	52.6%	26.5%	20.8%	675%
R600a	100° C	23.7%	72.8%	3.4%	1458%
	120° C	58.2%	37.8%	4.0%	975%
R717	100° C	29.4%	67.3%	2.9%	1346%
	120° C	62.1%	34.4%	3.5%	880%
RC318	100° C	36.5%	58.5%	5.0%	1157%
	120° C	58.7%	35.3%	6.0%	908%

R22 - Chlorodifluoromethane
R32 - Diffluoromethane
R114 - Dichlorotetrafluoroethane
R115 - Chloropentafluoroethane
R600a - Isobutane
R717 - Ammonia
RC318 - Octafluorocyclobutane

The thermodynamic calculations, in Table 8 indicate that when using 100°C geothermal fluid only about 1/3 of the energy generated can be used for useful work. At 120° about 1/2 of the energy generated can be used for useful work. Two factors explain the difference, the geothermal fluid at the higher temperatures contains more heat and the cycle efficiency is higher as indicated by the heat to be rejected. Both of these factors reduce the mass flow rate of geothermal fluid required, thus reducing the geothermal pumping power. The final result is a larger fraction of energy available for useful work. The maximum amount of useful work obtained is with R717, Ammonia, using 120°C geothermal fluid, 62.1% of the energy produced is available.

A complete cost analysis of the system was not made for the following reasons. Turbines using fluids other than steam are not readily available and would thus require an extension of existing technology. Because of this, cost estimating a turbine for the Binary System would be very difficult. Also, because of the temperatures expected and depths expected, the system does not appear economically feasible. The best case has an available energy output of only 62% of the electricity generated plus a very poor overall use of the enthalpy available in the geothermal fluid.

PRELIMINARY COST ESTIMATES AND NET ENERGY ANALYSIS - SYSTEMS IN ISOLATION OR IN COMBINATION

Net Energy Analysis

A method of assessing the comparative advantages of energy replacement systems is so-called net energy analysis. In this still new, and somewhat controversial method of project evaluation, the total energy for all materials and energy expended over the life of a project is calculated for each of the alternatives. The problem, at present, with net energy analysis is that the energy value of certain operations is only crudely known. The great advantage is that the method is entirely independent of monetary inflation and variable cost escalation of alternative fuels and materials.

For this particular project, the errors introduced by estimation are rather small because a large proportion of the energy is readily calculable operating energy. Net energy analysis was formally conducted for domestic hot water at one temperature of geothermal fluid and for space heating at three temperatures. In each case, the energy in the geothermal fluid (in situ) was taken as a free good, but all items of energy involved in constructing and operating the system were taken as an energy cost. The energy which would not be used in the existing central heating plant was taken as an energy credit (benefit). The net benefit over a 15 year life, in BTU's and as a percent of energy now being expended, was then calculated.

The following method was used to determine energy of construction: 1. Well drilling: Information from a drilling contractor on fuel expenditure per 100 ft. depth in our type of formation. 2. Pipe and heat exchanger: Published figures on coal and gas consumption for iron and steel making, plus design weight of metal used (Omitted: Energy of mining and transporting ore and coal, of fabrication of heat exchangers). 3. Insulation: Heat of formation of design amount of insulating material. 4. Installation: Approximate figures on hourly fuel consumption of trenching and welding machinery plus standard hours of operation for specified job. The energy of operations was calculated based on natural gas, at 1,060,000 BTU/mcf, as the fossil fuel. The electrical equivalent was computed at 30% overall efficiency of conversion. The campus usage was computed at 800,000 BTU/Mcf.

Table 9 shows the analysis for domestic hot water to 7 buildings over a 15-year period assuming no change in present demand. The calculation is for a geothermal fluid at 176°F (80°C), the lowest temperature anticipated. A net savings of 89.7 percent of fossil fuel now being used is predicted; this amounts to about 1.2 billion cubic feet of natural gas saved over a 15-year period.

It was not felt necessary to present formal analyses for the higher geothermal fluid temperatures. The savings (net benefit) is slightly over 92% at 100°C and rises to almost 95% at 120°C.

Turning to space heating of buildings, Table 10 shows net energy analysis results for space heating of 16 buildings. In this case

Table 9

NET ENERGY ANALYSIS - DOMESTIC HOT WATER HEATING

Total energy expended on project, by category, in 15 years, aside from the geothermal resource 80°C (Considered free and renewable, in situ).

Well Drilling	19,530,000,000 BTU
Pipe Fabrication	4,720,000,000
Insulation	20,000,000
Pipe Installation	50,000,000
Heat Exchanger	138,000,000
Maintenance & Operations	141,000,000
Pumping	126,283,000,000
Total (Fossil Energy)	141,882,000,000
Fossil Energy NOT Used (Nat. Gas Use Replaced)	1,240,905,000,000 BTU

NET FOSSIL ENERGY SAVINGS: 89.74%

calculations were performed for three choices of geothermal fluid temperature, because of the significant rise in savings with increase in that variable.

An explanation of the lower absolute savings (benefits) and lower percentage savings as compared with the domestic hot water case is in order. The lower absolute savings is partly a matter of the factors affecting the percentage, as explained next, and partly because the total 15-year space heating demand of the 16 selected buildings is only 82% of the 15-year domestic hot water demand of the seven building initially selected for the latter application. The percentage savings is lower for several reasons. In order of importance, they are: 1. The higher design reinjection temperature required for space heating heat exchanger operation, which increases the operating energy cost for well pumping. 2. The need to install larger heat exchangers and a very long and large (14-inch) recirculation pipeline, and 3. The cost of pumping in the circulation line.

Table 10

NET ENERGY ANALYSIS - SPACE HEATING OF 16 BUILDINGS

Total energy expended on project, by category, in 15 years.

The geothermal resource, at the various temperatures indicated is considered free and renewable, in situ.

Well Drilling	20,000,000,000	BTU
Pipe Fabrication	27,150,000,000	
Trenching & Pipe Installation	120,000,000	
Heat Exchangers	451,000,000	
Insulation	80,000,000	
Maintenance	150,000,000	
Circulation Pumping	11,949,000,000	
Sub-Total, All Temperatures	59,900,000,000	BTU or
At 80°C, G.F. Temp.		
Energy for Well Pump	218,955,000,000	BTU
TOTAL Expended	278,855,000,000	BTU
Natural Gas Replaced:	1,137,709,000,000	BTU
Net Benefit	858,854,000,000	BTU or 75.5%
At 100°C, G.F. Temp.		
Energy for Well Pumping	115,239,000,000	BTU
TOTAL Expended	175,139,000,000	BTU
Net Benefit	962,570,000,000	BTU or 84.6%
At 120°C, G.F. Temp.		
Energy for Well Pumping	78,198,000,000	BTU
TOTAL Expended	138,098,000,000	BTU
Net Benefit	999,611,000,000	BTU or 87.9%

The respectable 75.5% saving at 80°C turns out to be rather difficult to justify in dollar terms in the absence of an escalation factor for gas. And, even the 87.9% savings at 120°C will not quite make the amortization period of 15 years, on the assumption of level costs for gas and electricity. Part of the problem is the high investment in plant to be used only six or seven months a year, and this aspect of the problem suggests combination of two or more applications as a possible cost-reducing solution.

Formal net energy analysis has not been performed on the cooling option. The dominant role of pumping energy in that application means that the total energy savings for the standard assumption of pumping depth would be approximately the 40% savings indicated by the ratio of 612 kilowatts required to 1014 kilowatts replaced.

Complete net energy analysis has not been performed on combined operations, but an indication of the general outcome can be inferred from the thermal effectiveness ratio of pumping presented in Table 11. In general, the higher the thermal effectiveness of pumping, the higher the net energy benefit. To obtain a crude approximation of the fraction of energy savings, use the figure in the last column of Table 11 as the numerator, then add 1.2 to this figure to obtain the denominator.

Combined Domestic Hot Water and Space Heating

Combined domestic hot water and space heating is feasible with economics of pumping and of scale of 100°C and 120°C geothermal fluid temperatures. A combination is not really feasible at 80°C, but side-by-side operation, using the same wells, is possible. At any of these temperatures, the great economics of the domestic hot water heating plant will serve to amortize the less economical space heating application well within the nominal 15-year project life. Based on the (unrealistic) level of fuel cost assumption, the amortization periods (in years) is shown below in Table 12.

The above figures are for the selected buildings described earlier. Increasing the size of the project to take care of all possible needs not requiring live steam (about 90% of the natural gas consumption) and allowing for an escalation of natural gas prices, the combination is even more favorable. An amortization period of only six years would be possible

Table 11

THERMAL EFFECTIVENESS OF PUMPING GEOTHERMAL FLUID FOR DIFFERENT APPLICATIONS (1)

Application	G F Tem., °C & °F	Thermal Energy Extracted from Gf, BTU/1b	Thermal Effectiveness Ratio for Puming (2)
Domestic Hot Water	80 & 176	96	8.6
	100 & 212	132	12.2
	120 & 248	168	15.8
Cooling	120 & 248	36	2.6 (3)
Space Heating	80 & 176	50	4.0
	100 & 212	86	7.6
	120 & 248	122	11.2
Dom. H. W. & Space Heating	80 & 176	NOT FEASIBLE (4)	
	100 & 212	113.5	10.4
	120 & 248	156.1	14.6
Dom. H. W. & Cooling	120 & 248	68.7	5.9 (3)

NOTES:
(1) Relates to wells and transfer of heat at well-head heat exchanges only. Present building heater and cooler.
(2) Ratio of neat thermal energy transferred at well-head to thermal equivalent of well pumping energy. Net thermal energy defined as thermal energy extracted less thermal equivalent of pumping.
(3) Does not include the low COP of the refrigeration unit.
(4) Small gain in effectiveness offset by cost of system, particularly control instruments. This does not rule out side-by-side operation using the small wells.

Table 12

AMORTIZATION PERIODS FOR GEOTHERMAL ENERGY USE

Temp., °C	Domes, H. W.	Space Heating	Both Applications
80	4.8	22	10.5
100	4.6	18	9.3
120	4.4	17	8.8

assuming gas prices escalate 7% (compounded) more rapidly than electricity prices. This also assumes that the well-field is replenished at a sufficient rate to maintain the desired heat flow for 15 years.

Combination of Cooling with Hot Water and Space Heating

Cooling all or part of the campus would place a severe drain on the geothermal resource. As was explained earlier, the analysis of the cooling option has been carried out in terms of an "add-on" option, anyway, because it requires all the wells and equipment of the heating application. As was also explained, it does not appear to be a good marginal investment under present assumptions of conditions. Nevertheless, the savings in operating costs from domestic hot water application are sufficient that the additional capital expense could be paid off well within the 15-year nominal project life.

It should be pointed out that domestic hot water is not only the most profitable option, but it is also one which cannot be omitted for technical reasons if either of the space heating or cooling applications are chosen. This is because geothermal wells must be kept producing at some minimum rate consistently throughout the year, in order to avoid blockage of the well flow through precipitation of dissolved solids in the formation adjacent to the producing and/or injection well(s). So, irrespective of economics of scale or of combination, the domestic hot water application is an essential portion of any plant designed to use the campus geothermal resource.

Predicted Constraints

The feasibility of combining domestic hot water heating with space heating/cooling becomes a matter of IF. In other words, a technically acceptable and economically feasible combination may be possible, but certain conditions would need to exist for this to occur. These requirements are that:

1. Liquid petroleum fuel be available to fire the central heating plant boiler(s) to meet peak demand on cold winter nights.
2. Building heaters can be retrofitted for a 20° (36°F) hot water temperature drop at a cost which fits in with the overall economics.
3. Cost of electricity escalates at about half of the escalation rate for natural gas and petroleum.
4. The geothermal reservoir characteristics permit a variable pumping rate from 150 gpm to 2000 or more gpm without <u>any</u> long-term drop in well-head temperature.
5. The geothermal reservoir characteristics permit the above variable pumping rate with <u>no</u> short-term (hour-to-hour) drop if the temperature is 80°C (176°F), <u>or</u> with a moderate decrease of perhaps 5° to 10°C at maximum pumping rate if the temperature is 100°C (212°F) or higher at moderate pumping rates.

These five conditions pertain under a scenario where the university <u>can</u> obtain (at a price) most of its natural gas needs and does not face total cutoff except in an extraordinary emergency.

If a condition develops wherein NMSU is severely rationed on natural gas or faces regular curtailment or cutoff during the heating season, then all but the first requirement are subject to some revision. Requirement 3 will be modifiable depending on the price trade-off between liquid petroleum fuel and electricity. Requirement 4 could be relaxed to permit something like a 1°C loss per year, with a geothermal fluid initially at 100°C or higher. Requirements 2 and 5 are relaxable to a certain extent, depending on the trade-off on equipment over-design costs with cost of alternative fuel supply.

Comparative Demand and Pro-Rate Costing

Demand, in BTU/days, on the geothermal fluid for the three applications must be analysed for interaction effects to avoid unrealistic pro-rationing. Adjusted to a common base of one-half total campus demand, these figures are, in millions of BTU per day: Cooling (avg. June day), 582; Heating (avg. Jan day), 437; Domestic Hot Water (avg. weekday, acad. yr.), 528. Superficially, the attractiveness of combining domestic hot water heating with space heating/cooling should lie in the use of the same well(s) and in extracting more thermal energy from the geothermal fluid after having expended pumping energy to raise it to the surface. Calculations based on the average demand figures bear this out in that more thermal energy can be obtained by the combination than for space heating or space cooling demands alone. In every case, the thermal effectiveness of pumping is <u>lower</u> than when the application is domestic hot water heating only. Nevertheless, in some of these cases the interaction effects favor use of the combination, rather than side-by-side separate operation. This is because use of multiple, inter-connected heat exchangers will allow at least some recovery of what would otherwise be "waste heat" when operating the facilities in combination. This refers to waste heat from the heating/cooling operation - effectively there is none from the domestic hot water application.

The fossil fuel equivalent of the energy required to pump the geothermal fluid from the reservoir, pass it through heat exchangers and reinject it is about 10 BTU per pound (assuming a pumping depth of 2000 feet (610 meters). Barring unforeseen peculiarities in the solids content of the geothermal fluid, it should be possible to extract 96 to 186 BTU/lb from this fluid when used for the domestic hot water heating application only. The thermal effectiveness of pumping is then defined by subtracting the 10 BTU/lb from the figure appropriate for the reservoir temperature and application and dividing by 10. The results for all applications studied are summarized in Table 11.

One reason why the energy obtained per pound of fluid in various combinations is reduced below that for domestic hot water alone is that the pumping rate is determined by the heating/cooling demand and the resulting geothermal fluid flow is greater than needed to meet domestic hot water demands. In some cases of combining space heating and domestic hot water, the intermediate temperature levels available are not appropriate. It should be pointed out that the thermal effectiveness of pumping for any combined system is going to be a function of instantaneous demand. In one sense the figures in the last column of Table 11 are on the optimistic side, because they are calculated from average demands (the only figures available). If fluctuation in demand of the two services which are combined do not coincide, the thermal effectiveness ratio will change. In general, it is expected to drop, rather than increase, when peak demands come at different times of the day.

Returning to the IF's. If a severe, pure shortage of alternative fuel is not anticipated, the use of the geothermal resource to supply domestic hot water alone is the most favorable single option or combination of options for effective use of that resource. This factor is what makes the hot water option quite economically desirable at near-term alternative energy costs.

SECTION V

EXTENSION OF ECONOMIC ANALYSIS

An extended economic analysis has been conducted in two parts: the first involves the payoff period concept and the second uses the breakeven analysis. In both cases the various costs are determined for various possible geothermal temperatures in combination with different modes of possible usage.

THE PAYOUT PERIOD ANALYSIS

Let I be the rate at which natural gas costs increase annually and let J be the rate at which electrical rates increase. If G_n and E_n represent the gas and electric rates respectively in the year n, then

$$G_n = G_o (1 + I)^{n - 1}, \quad I = .065$$

$$E_n = E_o (1 + J)^{n - 1}, \quad J = .03$$

where G_o and E_o are the present rates. Both I and J are based on the figures of Hudson and Jorgenson [22]. Computations are made for the average rates G_A and E_A over the next fifteen years as

$$G_A = \sum_{n=1}^{15} G_n/15$$

and

$$E_A = \sum_{n=1}^{15} E_n/15$$

The average geothermal facility costs are computed as well as average yearly cost for the existing facility. Thus,

$$GEOCOST = MOG + (\text{Electricity Consumption})\ (E_A)$$

and

PCOST = MOP + (Gas Consumption) (G_A),

where MOG and MOP are the annual maintenance and operating costs for geothermal and existing facilities respectively.

In this analysis PCOST - GEOCOST is considered as income. Payout period then can be defined as the time required to amortize the capital expenditure at 6 percent annual interest.

Table 13 gives the payout periods for different configurations investigated in this study.

Table 13

PAYOUT PERIODS FOR ALTERNATIVES INVESTIGATED

Temperature (degrees)	Usage	Payout Period (Years)
80	90% all gas	5.8
89	Space Heating	2.2
100		1.8
120		1.7
80	Space Heating & DHW	10.5
100		9.3
120		8.5
80	DHW Only	4.8
100		4.6
120		4.4

BREAKEVEN ANALYSIS

In addition to I and J defined earlier, let K be the inflation rate (assumed to be .03 in this study) and L the rate at which capital is available (0.06). Let GECONS represent electricity consumed by the geothermal facility and PGCONS the gas consumption for the present system, then

$$GECOST_n = PMT_n + (GECONS)\ (E_n) + MOG_n$$

and

$$PCOST_n = (PGCONS)\ (G_n) + MOP_n,$$

where

$GECOST_n$ = Cost for the geothermal facility in year n,

$PCOST_n$ = Cost for the present system in year n

$MOG_n = MOG_o(1 + K)^{n - 1}$

$MOP_n = MOP_o(1 + K)^{n - 1}$

PMT_n = Annual Payment for Geothermal Equipment

In this particular analysis the capital cost is amortized over ten years, that is $PMT_n - 0$ for $n > 10$.

The combined plots of $GECOST_n$ and $PCOST_n$ against n is the break-even graph. As an example, consider the graph for "90% of all gas at 80°C" - Figure 25. From this we see that approximately for the first two years the geothermal facility will cost more to operate including amortization than the present one, but after the third year it will result in a substantial savings (as high as $90,000 in the 15th year). All the other graphs can be analyzed similarly as follows: Figures 26, 27 and 28 deal with geothermal application to domestic hot water usage. As can be seen in the domestic hot water case, the geothermal alternative is financially more favorable than the present system, from the beginning onward.

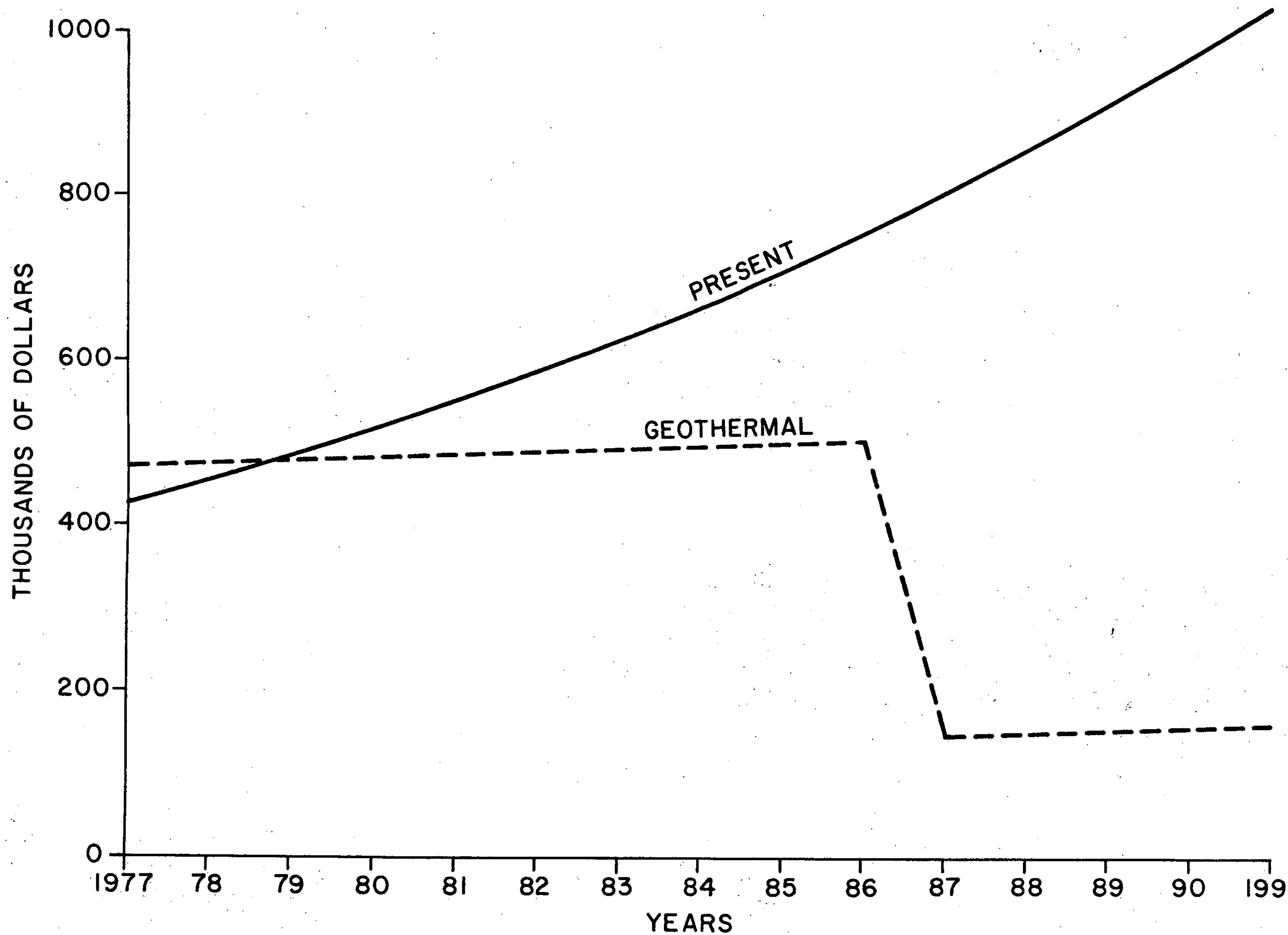


FIGURE 25
90% OF ALL GAS AT 80°C

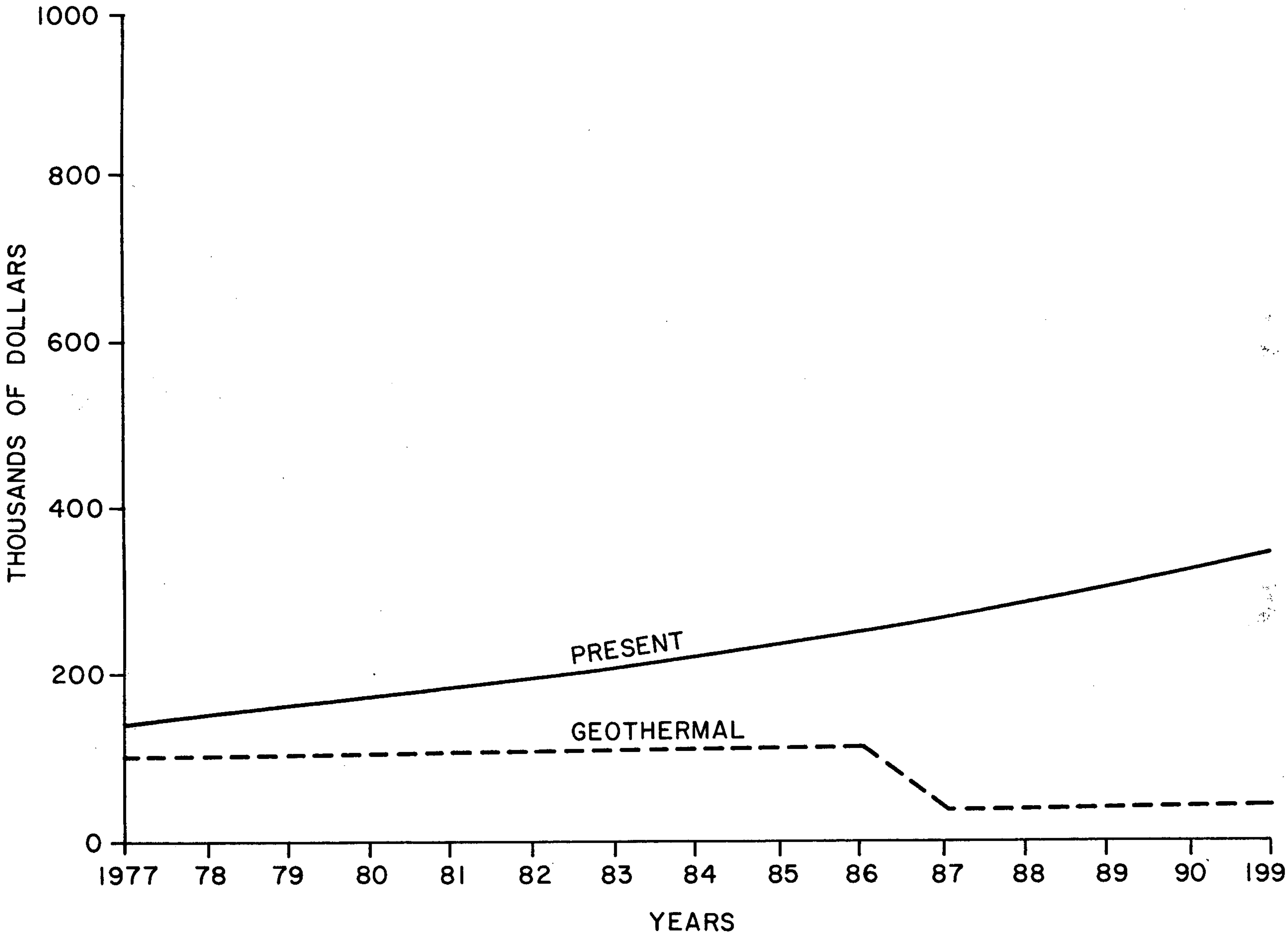


FIGURE 26
DOMESTIC HOT WATER FROM 120°C GEOTHERMAL FLUID

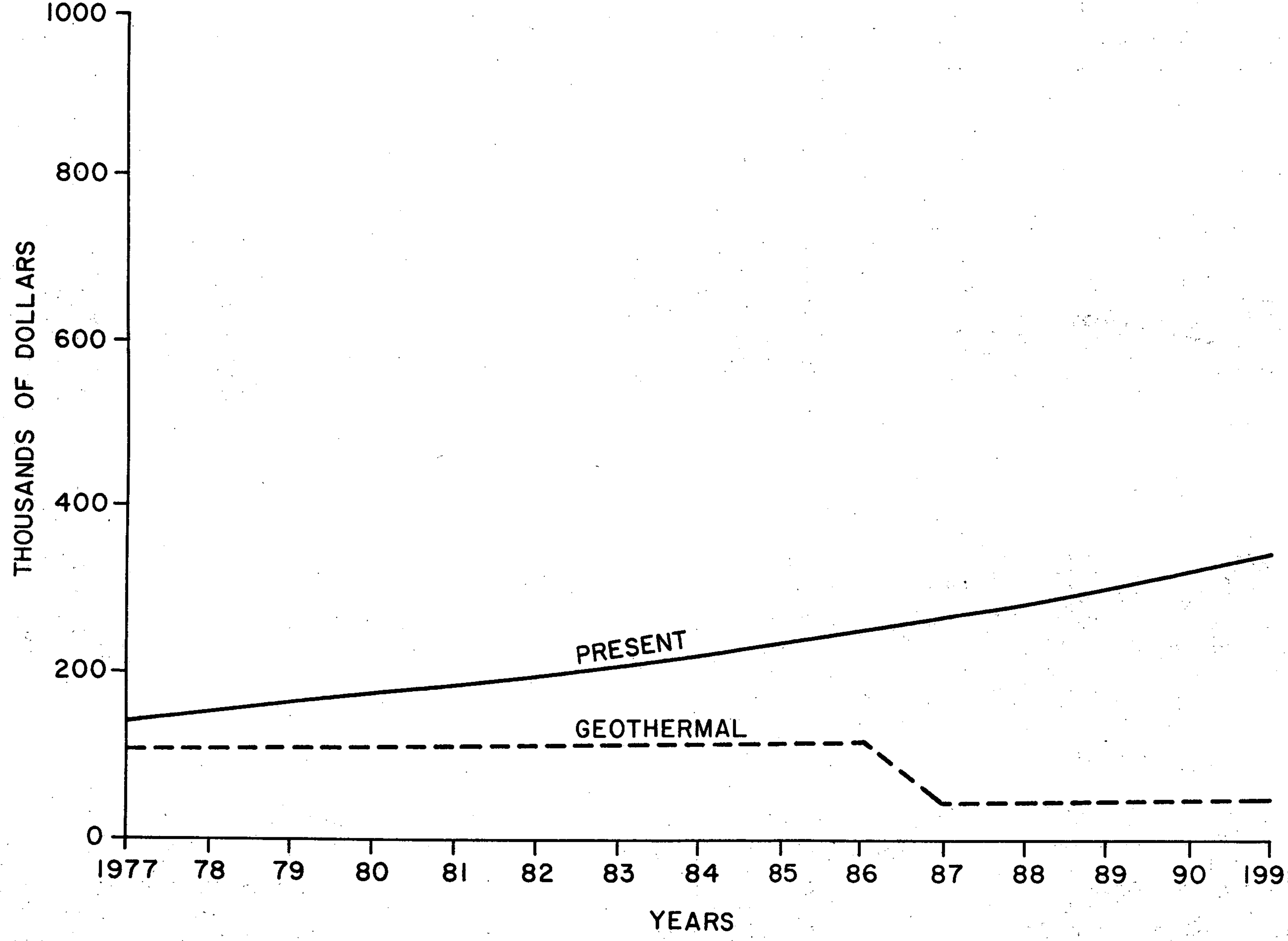


FIGURE 27
DOMESTIC HOT WATER FROM 100°C GEOTHERMAL FLUID

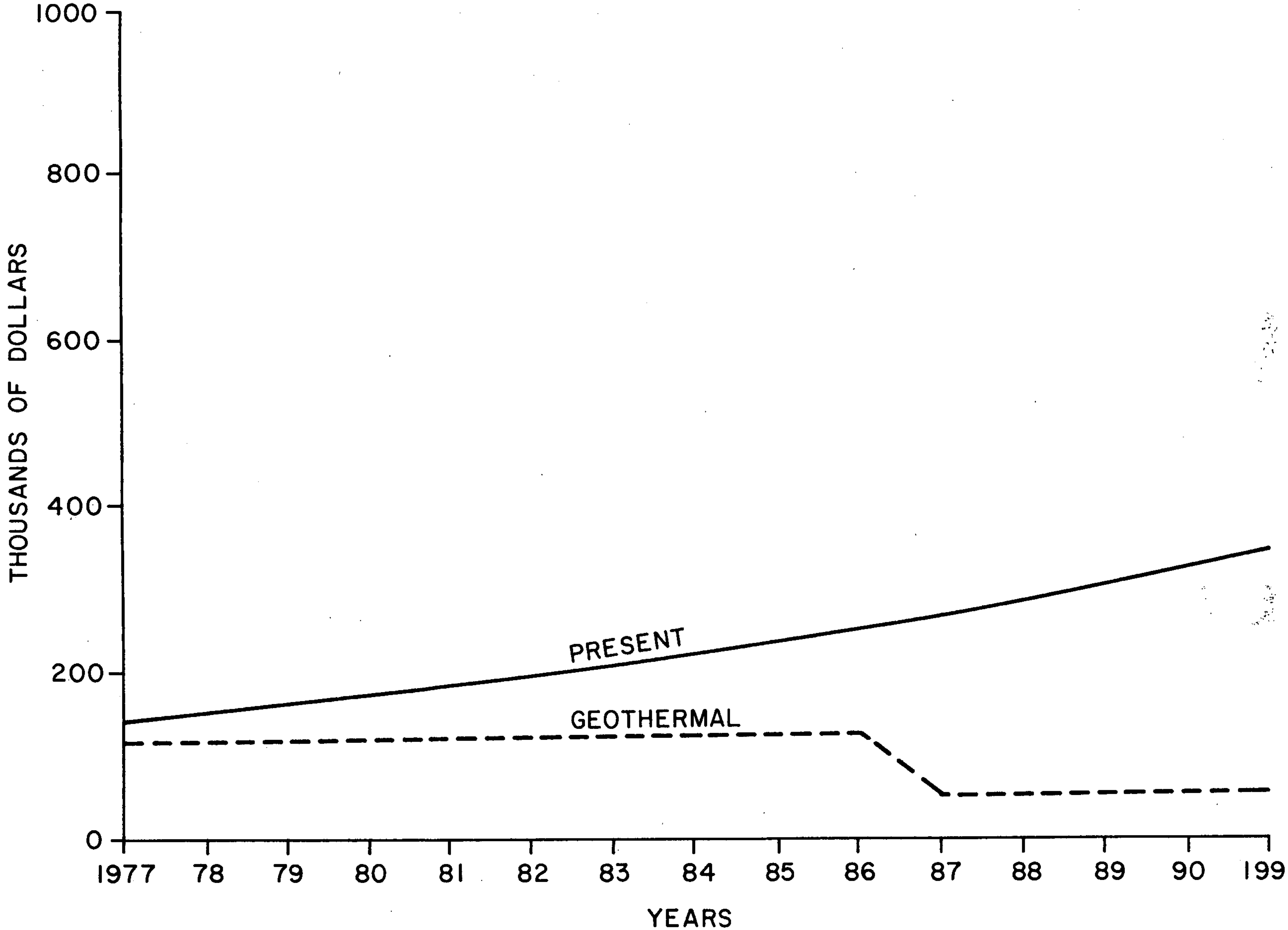


FIGURE 28
DOMESTIC HOT WATER FROM 80°C GEOTHERMAL FLUID

In case of space heating combined with domestic hot water, the following are approximate breakeven points:

i. Geothermal fluid at 120°C (Figure 29): The geothermal facility becomes more profitable after the 4th year.

ii. Geothermal fluid at 100°C (Figure 30): The breakeven point is about 4½ years, and

iii. Geothermal fluid at 80°C (Figure 31): Geothermal energy is better after the 6th year.

If the use of geothermal energy is for space heating only, then the breakeven points fall at 9, 9½, 10 years for fluid temperatures of 120°C, 100°C, and 80°C, respectively as seen in Figures 32, 33, and 34.

As can be seen from both analyses, the usage of geothermal energy for domestic hot water is very highly desirable. The second desirable usage is for the combination of space heating and domestic hot water. It appears that the use of geothermal energy for space heating only, though profitable, is the least desirable alternative amongst those investigated here.

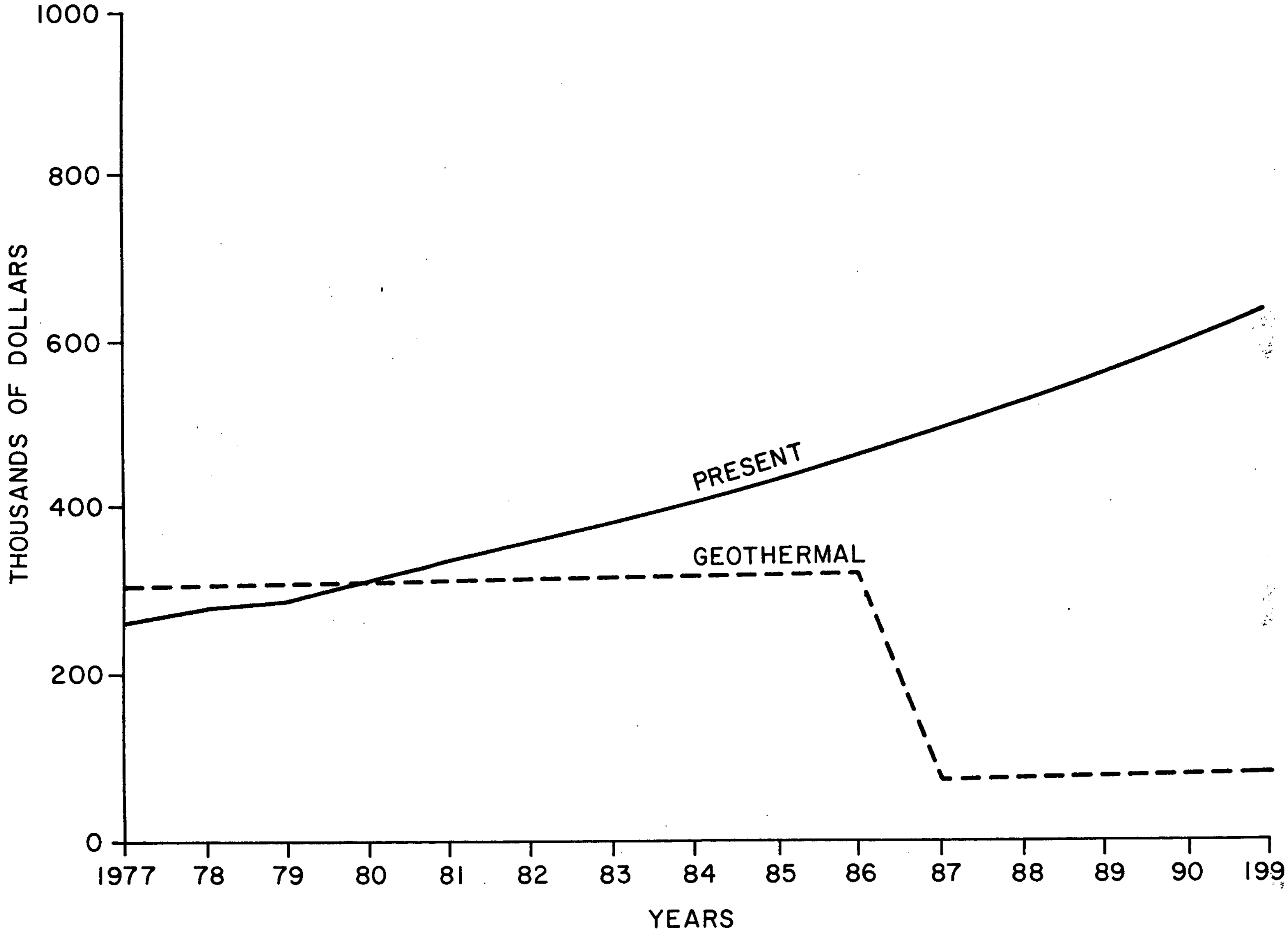


FIGURE 29
SPACE HEATING AND DOMESTIC HOT WATER **FROM 120°C**
GEOTHERMAL FLUID

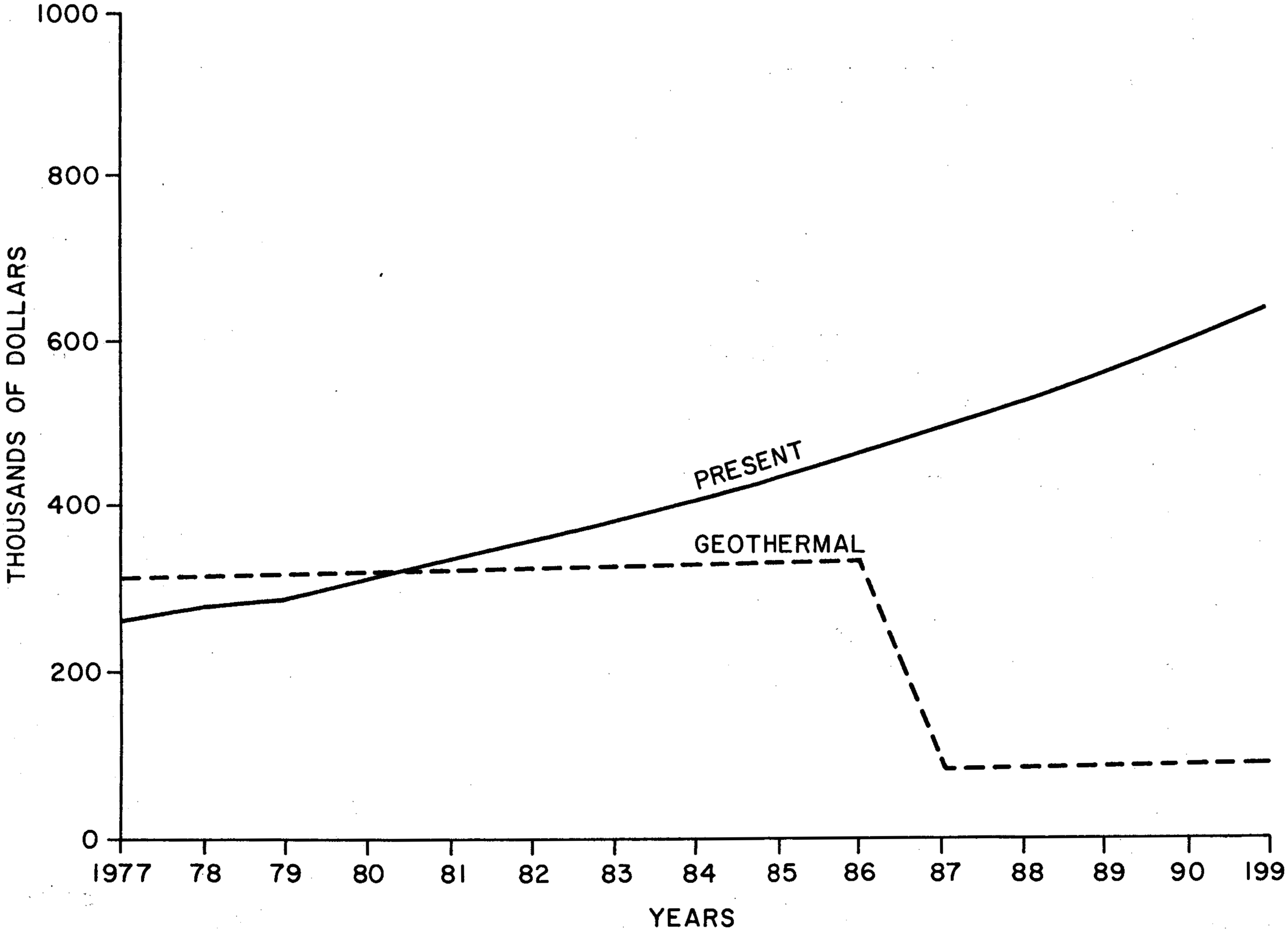


FIGURE 30
SPACE HEATING AND DOMESTIC HOT WATER **FROM 100°C GEOTHERMAL FLUID**

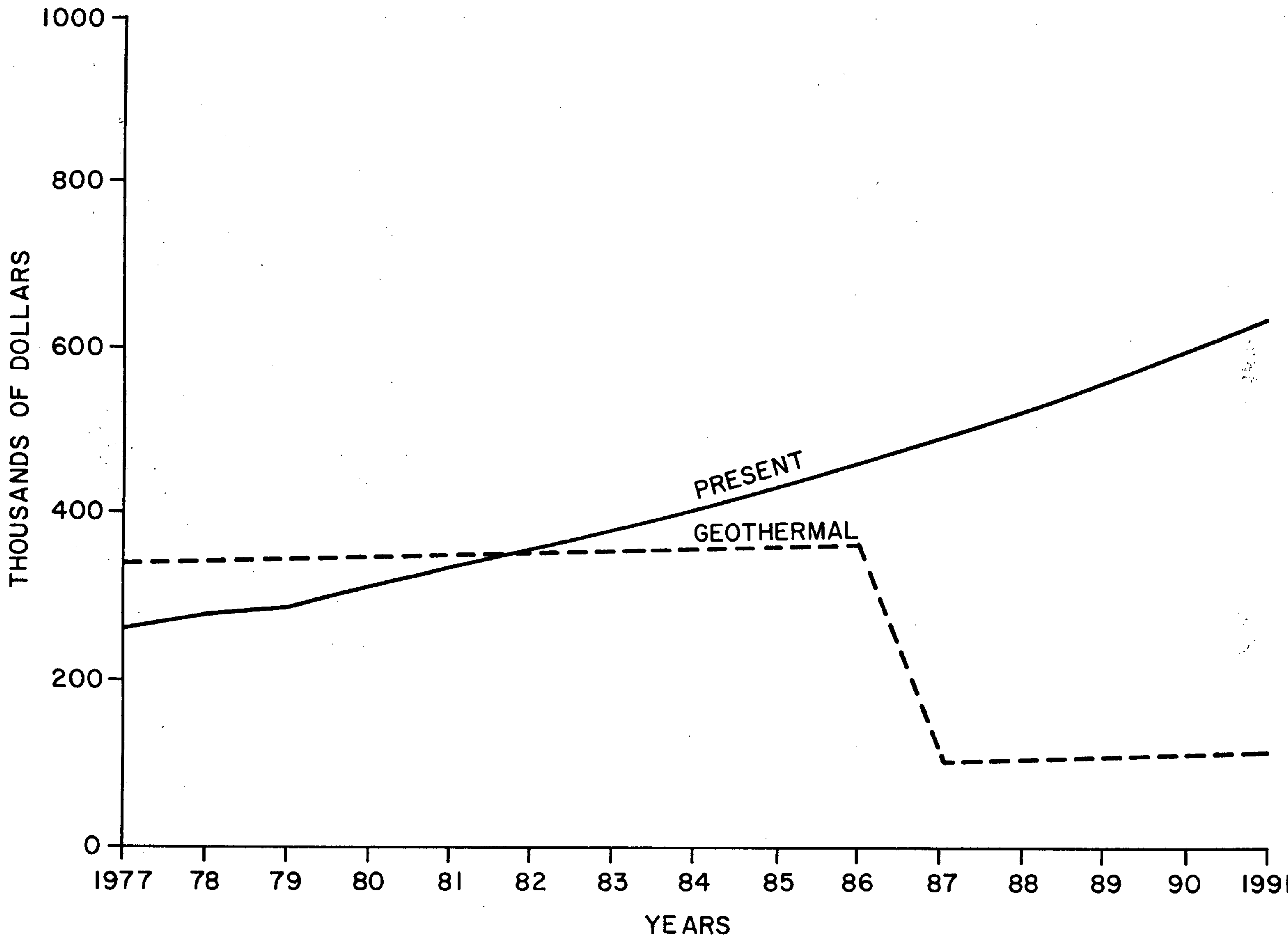


FIGURE 31
SPACE HEATING AND DOMESTIC HOT WATER FROM 80°C GEOTHERMAL FLUID

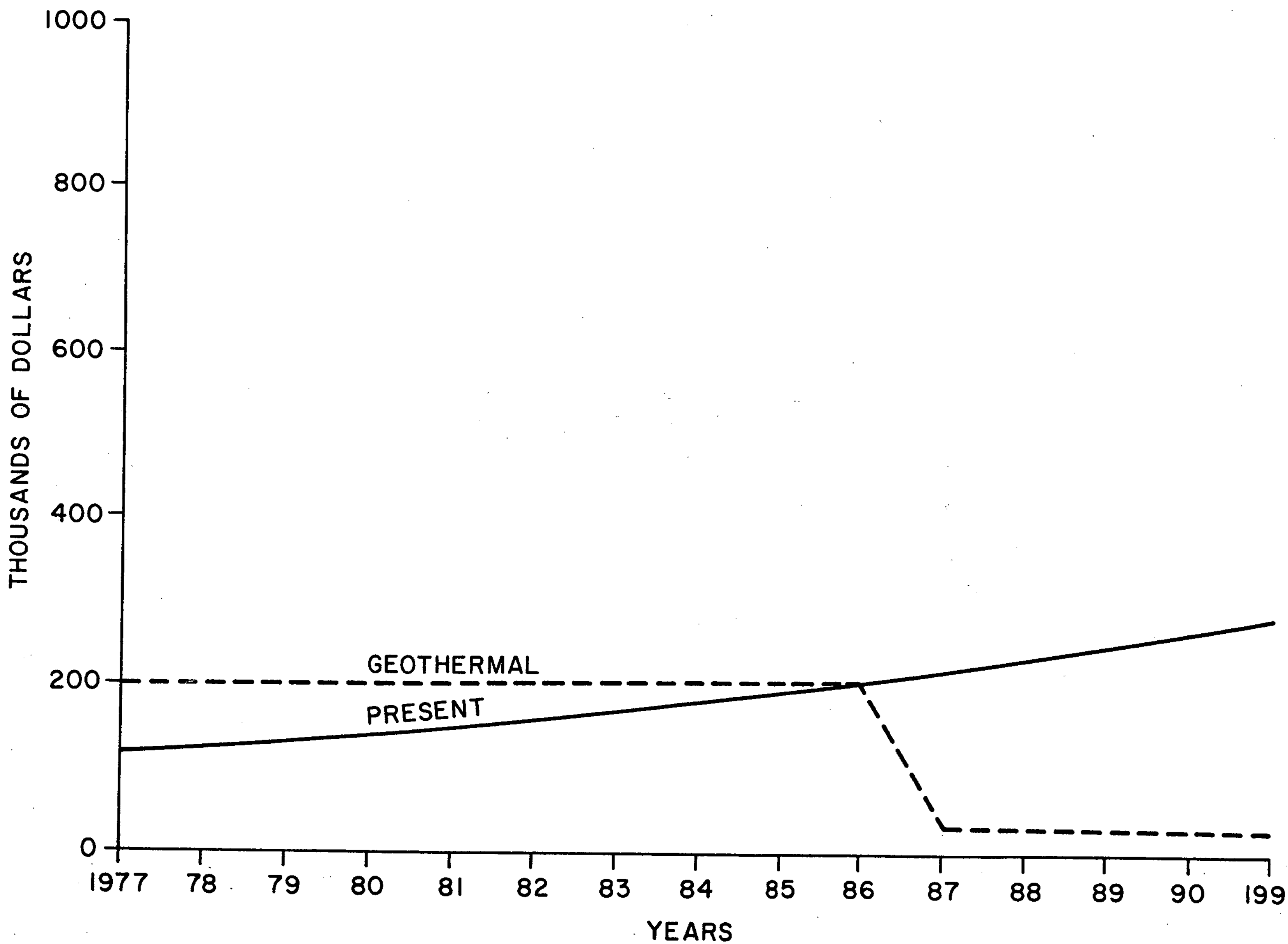


FIGURE 32
SPACE HEATING FROM 120°C GEOTHERMAL FLUID

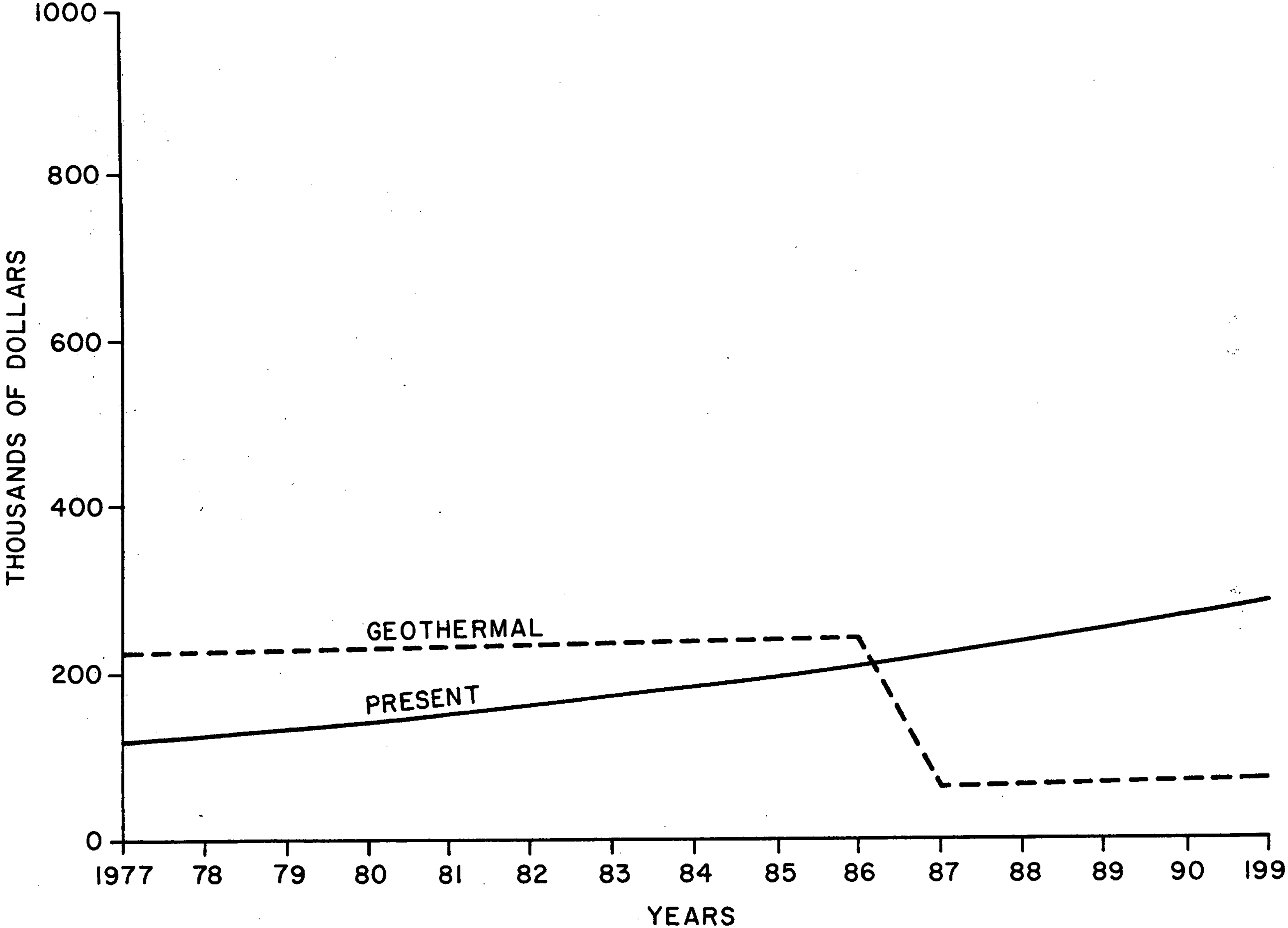


FIGURE 33
SPACE HEATING FROM 100°C GEOTHERMAL FLUID

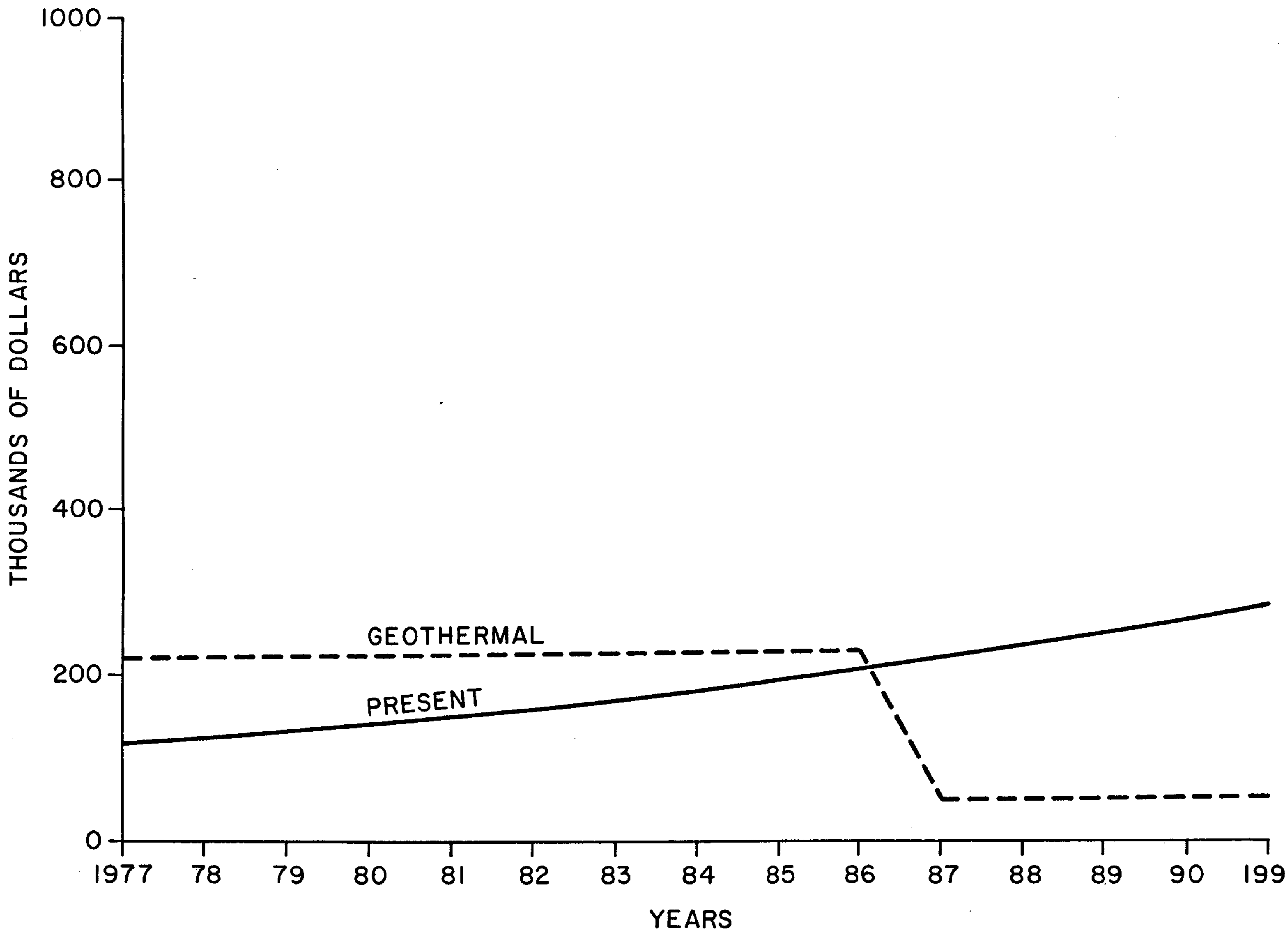


FIGURE 34
SPACE HEATING FROM 80°C GEOTHERMAL FLUID

SECTION VI

LEGAL AND ENVIRONMENTAL CONSIDERATIONS

OUTLINE OF THE GEOTHERMAL ENERGY ENVIRONMENTAL IMPACT ANALYSIS

Environmental impact analysis should be made to provide guidelines for the evaluation of the various candidate geothermal energy conversion concepts to facilitate the engineering design phase. This not an environmental impact statement for this study but rather a review of possible environmental impacts which should be considered as the design of a proof-of-concept study is being completed. This approach permits the implementation of design options to minimize the negative environmental impact and maximize the environmental benefits.

The activities involved in the geothermal project are shown in Table 14. These are major activities during the life of the project. The size and level of each activity may vary significantly. The Table also shows the environmental impact for each activity. These impacts consider the effects of ecological factors in addition to the effects of air, water, wildlife, vegetation and topography, etc. The Table further illustrates qualitative assessment of impact in terms of magnitude duration and probability of occurrence. When assessment is not rated then it is considered that evaluation is subjective. Mitigating factor are stated wherever applicable and not all impacts have mitigating factors. The important environmental factors are those wherein the probability of occurrence is high, the life of impact is considerable and the magnitude of potential effect is large.

Table 14

ENVIRONMENTAL IMPACT ACTIVITIES FOR GEOTHERMAL ENERGY DEVELOPMENT

Environmental Activity	Possible Impact	Probability Of Occurrence	Magnitude	Duration	Mitigation Procedures
Drilling Operations	Air				
	a) Dust	High	Large	Short	Watering down during drilling
	b) Steam release	High	Large	Short	Use condensers
	Groundwater				
	a) Aquifer injection	Low	Moderate	Short	Casing design
	b) Aquifer supply escape	Low	Short	Small	Casing design
	Surface Water				
	a) Mud pollution	Low	Moderate	Short	Portable Containers
	b) Water supply-use	High	Small	Short	
	Vegetation				
	a) Destruction in work area	High	Short	Small	Minimal Sight vegetation
	Wildlife				
	a) Destroy Endangered species	Low	Small	Long	
	b) Establish attracted species	High	Small	Short	
	c) Habitat Destruction	Low	Small	Long	
	Topography				
	a) Grading for site & road	High	Moderate	Short	

Table 14 (Continued)

Environmental Activity	Possilbe Impact	Probability Of Occurrence	Magnitude	Duration	Mitigation Procedures
Drilling Operations	b) Erosion from runoff	High	Small	Long	
	c) Drill mud pond	High	Small	Short	Restore site
	Noise				
	a) Equipment	High	Moderate	Short	
	b) Effluent discharge	High	Large	Short	Use of mufflers
	Aesthetics				
	a) Drilling rig	High	Moderate	Short	
	b) Effluent plume	High	Large	Short	
	Archaeology				
	a) Site destruction	Low	Small	Long	
Geothermal Fluid Extraction	Groundwater				
	a) Contamination	Low	Moderate	Long	Casing design
	Geologic Stability				
	a) Subsidence	High	Large	Long	Reinjection
	b) Fault zone activity	Moderate	Moderate	Long	Seismic survey
Geothermal Fluid Transmission	Surface Water				
	a) Rupture Contamination	Low	Moderate	Short	Pipe design
	Vegetation				
	a) A long pipe line	High	Small	Long	
	b) Rupture destruction	Low	Moderate	Short	

Table 14 (Continued)

Environmental Activity	Possible Impact	Probability Of Occurrence	Magnitude	Duration	Mitigation Procedures
Geotheraml Fluid Transmission	Aesthetics				
	a) Overland Visibility	High	Small	Long	
Reinjection	Groundwater				
	a) Aquifer seepage	Low	Small	Long	Casing design
	Geologic Stability				
	a) Fault zone friction decrease	Low	Moderate	Long	Avoid fault zones
Effluent Surface Disposal	Air				
	a) Emission of noncondensibles	High	Large	Long	
	Groundwater				
	a) Seepage from runoff	High	Large	Long	
	Surfacewater				
	a) Brine pollution	High	Large	Long	
	Aesthetics				
	a) Vapor plumes	High	Large	Long	
	Wildlife				
	a) Changes in habitat	Low	Small	Long	
	Vegetation				
	a) Destruction by brine	High	Large	Long	
	b) Growth by fresh water	Low	Small	Long	

IDENTIFICATION OF THE REGULATORY AND INSTITUTIONAL IMPEDIMENTS TO DEVELOPMENT OF GEOTHERMAL ENERGY

The regulation of a geothermal resource should be logically related to the nature of the resource and institutional arrangement should properly fit its development. However, legal institutions have not been rationally structured. The legal aspects of Geothermal development are a product of our past endeavors in state and federal mining and water laws. It appears that legal institutions created for other purposes basically have hampered geothermal energy utilization.

Geothermal energy exploration is of recent origin while laws dealing with development of water and mineral resources have been enforced for many years. These laws differ from state to state somewhat and often differ with regard to public lands in comparison with private lands. If the resource is wholly in the private lands then the laws are precisely clear: that is, the owner of surface of the land owns everything that is under it. In the arid west, laws related to water rights are different. The western states follow the doctrine of prior appropriation while in the east the riprian rights prevail.

In the early development of the west there were comprehensive laws regulating mineral resources. In 1872, the U.S. Congress passed the General Mining Law governing the extraction of minerals and decreed:

1. Open exploration in the federal domain;
2. Acquisition rights to minerals on public lands by discovery claim filing;
3. Title acquisition to surface land for nominal fee of federal deed known ad "patent;" and
4. Production of minerals without patents and without payments of any royalties or rent.

The size of the claim was restricted to 20 acres.

The U.S. Congress restructured the laws again in 1920 and specific minerals were removed from general mining laws under one location-patent system and placed under a leasing plan. Under this act, and subsequent legislation, oil, gas, shale, phosphate, ore, sulphur, potassium, sodium, tar sands, etc., on public lands were made subject to competitive or non-competitive bidding. In case of minerals the limiting factor for bidding was the existence of workable deposits, while in case of gas and oil it was the existence of known geologic structure. In the Materials Act of 1947, Congress has provided for outright sale of certain minerals. The early congressional debate centered around which of these three systems of mineral rights acquisition should apply to geothermal exploration. It became evident, as the debate progressed, that these three systems are deficient and required modification prior to application to geothermal explorations and use.

Water resources development can be considered as one possible model for geothermal energy. The basis for this model rests on the fact that geothermal energy found in nature is an exploitable form only in association with water in its vapor or liquid forms. Immediately it was clear that if geothermal energy is treated as water for regulatory purposes, then many unique problems arise.

In 1970 Congress passed the act which was signed by the President as the "Geothermal Steam Act." The act resolved several open questions on geothermal energy development on federal lands and left some doubts.

Congress defined in this act "Geothermal Steam and Associated Resources" to include all products of geothermal activity, including steam, water, gas, brines, heat, etc. This definition did not solve questions as to how other aspects of mineral and water resources law applies to geothermal energy. Congress, by not stating explicitely that geothermal resources are either water or minerals left open several issues from the development prespective of geothermal energy. One such issue is the degree of applicability of state water laws to a geothermal resource on federal laws. The second such issue is addressed to mineral reservations by the U.S. patents given under the Homestead Acts. The third problem of concern deals with the rights to locatable minerals underlying the land covered by geothermal lease. This can be interpreted as another person could obtain rights to mineral on the same tract of land held by the geothermal leases.

Geothermal leases were subject of debate in Congressional hearings associated with geothermal hearing. Potential users urged broad availability while the conservationists argued for availability of federal lands with certain restrictions. The final solution was elimination of national parks, recreation areas, wild life management areas, etc. from leasing to geothermal development.

The competitive bidding system for geothermal resources was a hotly debated issue. Opponents of the issue argued that competitive leasing would discourage exploration and security of investment in geothermal exploration. Congress after considerable hassle adopted a bifurcated system in which competitive and non-competitive leasing is permitted. The limiting factor in determining leases is whether or not the land is in a "known geothermal resources are (KGRA)."

Since the main direction of the act and enabling legislation is towards competitive bidding on leases, the resultant effect should be discouragement of "wildcat" exploration. These provisions most likely discourage small independent businesses from the geothermal leasing process. The discouragement results in part because they cannot be rewarded for their exploration activities and the bonus bidding system discriminates subjected to competitive leasing or at least the encouragement of such practices. California and Alaska have tackled the problem of exploration and prospecting for geothermal energy on lands which are not classified as KGRA's. State leasing provisions are similar to that of the federal government, however, they differ in some particulars. In California the primary leasing term is 20 years and renewals of up to 99 years are allowed as long as there is a commercial production of steam. New Mexico provides for a 5-year primary term and 5-year renewals thereafter. Alaska has 10-year primary term and 40-year renewals up to a total of 99 years. These should be compared with federal law which has 10-year primary term and 40-year renewal periods. Royalty provisions differ in each state.

The problem which is going to hinder geothermal energy development in the future is overlapping regulatory jurisdictions of state, federal and local government with respect to acquisition of rights to geothermal exploration, drilling, development, production, and utilization. This results from the fact that state, federal, county and local government are involved with regulation of private state and federal lands.

SECTION VII

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